RELATIONSHIP BETWEEN TRI-BAR RESOLUTION AND CONTRAST FOR OPEN SKIES ACQUISITION FILMS

USAF/OSMPF

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Title: Relationship Between Tri-Bar Resolution and Contrast for Open Skies Acquisition Films.

Summary: Concerns have been raised in the Open Skies Community that sensitometric contrast changes caused by process variations might significantly alter the resolving power characteristics of Open Skies Acquisition Films during acquisition missions. To determine the effect of processing induced sensitometric contrast changes on the resolution capabilities of the acquisition films 3404, 3412, and SO-050, tri-bar target images of low and high test object contrast were exposed onto these films. The films were processed in Kodak Versamat 641 Developer using a Kodak Versamat 1140 Processor. Degree of development was altered by varying the transport speed of the processor in order to effect changes in image contrast. Exposure levels for the tri-bar images were varied such that peak resolution values could be determined for each processing condition. Results are summarized for each film below.

Discussion:
Procedures used for this experiment are discussed below.

Sensitometry

The featured films were exposed on a Kodak 1B Sensitometer using the conditions shown below in Table #1. All exposures were aged 24 hours prior to processing.

Table #1: Exposure Conditions for Acquisition Films on the Kodak 1B Sensitometer.

Film	Exposure Condition	Log Exposure at 11th Step (Log Lux Seconds)
3404-0451	3000°K + D/L Filter 1/100 sec	2Bar 0.57 or -1.43
3412-1561	3000°K + D/L Filter 1/50 sec	2Bar 0.87 or -1.13
SO-050-0015	3000°K + D/L Filter + 0.59 ND 1/100 sec	3Bar 0.98 or -2.02

*Note 3000°K + Daylight Conversion Filter produces effective 6100°K.

Tri-Bar Resolution

Tri-bar resolution targets were exposed onto the featured acquisition films using the Advanced Micro Camera AM-1. This camera was designed to expose three sets of 11 targets onto a test film such that each exposure differed from the previous one by 0.2 log E. Exposure was varied by intensity within each exposure series. Exposure conditions were pre-determined to produce a peak resolution value in the middle of each exposure set. After processing, the strips were read by two readers. The readings were then averaged for the three image sets. Average data was then plotted on a relative log exposure axis with a sensitometric curve overlaid on the same plot (These plots are included in the Appendix). The sensitometric curve was prepared by reading the density of low contrast resolution images with a pinhole densitometer*, and plotting them in the

same X-Axis position with their respective resolution data points. This made it possible to relate developed density of the resolution targets to the exposure required to produce that density on the film **as** determined using sensitometric curves for Kodak 1B Sensitometer exposures (These curves **are** included in the Appendix). This was done by finding the Log Lux-Seconds on the 1B process sensitometric curve using the density values shown on the resolution plots.

*A pinhole densitometer was used for resolution images on SO-050 and 3404 films. However, due to the greater image reduction required for the 3412 film, a PDS microdensitometer was used to determine the density of the low contrast images.

The contractor chose to determine peak resolution using image sets in which the exposure on the film was varied, since the film's peak resolution is in part affected by developed silver grain morphology and density in the processed emulsion layer which can **vary** with changes in processing conditions. Of course, resolution is also affected by light scatter, grain size of the unprocessed emulsion, emulsion thickness, and halation. Hence, resolution exposures must be adjusted as process conditions are varied in order to assure determination of peak resolution for each condition.

Two test object contrasts for tri-bar resolution images were used in this experiment. A high contrast target exhibiting a test object contrast of 1000:1 was used to determine maximum resolution capability of the film under ideal conditions. A low contrast target of 1.7:1 test object contrast **was** used to better simulate the film's resolution performance under actual aerial photographic conditions. The image reduction factors on the AM-1 camera were 99X reduction for 3404 and SO-050 films, and 255X reduction for 3412 film.

Processing Conditions

A Kodak Versamat 1140 Processor was used with 641 Developer to process all of the featured films. Changes in thruput speed were varied for each film in order to produce levels of development that ranged from significant over development to significant under development. Development temperatures were determined by using standard process conditions used by the Contractor for each film.

Sensitometric Measurements

ISO-A Gamma: Contrast was measured on the 1B exposed sensitometric curves for each film/process combination using the ISO-A standard (ANSI/IS0 7829-I 986, ANSI PH2.34-1987). Using this method, a lower point is found on the sensitometric curve at 0.3 density above base plus fog density. An upper point is found at a density 1 .O higher than the lower point. The ISO-A gamma is the slope of a straight line connecting these two points.

ISO-A Speed (Formerly EAFS): Under the ISO-A standard (ANSI/IS0 7829-1986, ANSI PH2.34-1987), the speed point **H** is determined as the lux-seconds required to produce a density of 0.3 above base plus fog on the sensitometric curve. The speed is then determined by the following formula.

ISO-A (EAFS) Speed = 1.5/H

Results:

Contrast and resolution values for each film are shown below in Tables #2, 3 and 4 respectively for 3404, 3412, and SO-050 films. Nominal sensitometric values for Open Skies Processes for these films are shown in Table #5.

Table #2: Contrast and Resolution Measurements for 3404-0451 Film in Kodak Versamat 641 Developer at 109°F.

Process Condition	ISO-A Speed	ISO-A Gamma	Resolution (c/mm) ± 2 Sigma 1.7:1 TOC	1000:1 TOC
2.5ft/min (192 sec)	321	1.35	37±12	68±12
5.0ft/min (96 sec)	423	1.37	43±7	83±12
7.5ft/min (64 sec)	344	1.45	45±5	93±13
10 ft/min (48 sec)	306	1.48	43±10	90±17
20 ft/min (24 sec)	202	1.15	48±5	99±11
40 ft/min (12 sec)	109	0.70	48±4	99±19

Table #3: Contrast and Resolution Measurements for 3412-1561 Film in Kodak Versamat 641 Developer at 105°F and 90°F where Indicated.

Process Condition	ISO-A Speed	ISO-A Gamma	Resolution (c/mm) ± 2 Sigma 1.7:1 TOC	1000:1 TOC
10 ft/min (48 sec) 105°F	106	1.60	83±11	229±56
15 ft/min (32 sec) 105°F	81	2.20	99±31	240±57
22 ft/min (26.4 sec)105°F	61	2.20	97±27	276±3
30 ft/min (16 sec) 105°F	57	2.20	124±27	275±54
40 ft/min (12 sec) 105°F	43	1.90	122±23	259±67
40 ft/min (12 sec) 90°F	32	1.45	110±19	281±47

Table #4: Contrast and Resolution Measurements for SO-050-0015 Film in Kodak Versamat 641 Developer at 89°F.

Process Condition	ISO-A Speed	ISO-A Gamma	Resolution (c/mm) ± 2 Sigma 1.7:1 TOC	1000:1 TOC
5.0ft/min (96 sec)	686	1.60	27±5	61±8
7.5ft/min (64 sec)	597	1.25	29±6	63±12
10 ft/min (48 sec)	508	1.15	30±8	56±15
12 ft/min (40 sec)	453	1.05	29±6	62±9
20 ft/min (24 sec)	267	0.83	28±3	62±7
40 ft/min (12 sec)	116	0.60	30±3	74±12

Table #5: Nominal Sensitometric Values for Open Skies Acquisition Films*

Film	ISO-A Speed	ISO-A Gamma
3404	150	1.20
3412	45	1.80
SO-050	640	1.00

* Values disclosed to the Contractor by the Sponsor.

Data packages are attached in the Appendix for each of the featured films. These include,

- Summary spread sheet for measured data;
- Sensitometric curves for each film through each process condition that were prepared using the Kodak 1B Sensitometer;
- Resolution vs. ISO-A Gamma charts for each film:
- Resolution vs. Process Thruput Speed charts for each film;
- Resolution vs. Relative Log Exposure and Developed Density charts for each film and process condition.

Conclusions:

3404 Film

1. No significant change in tri-bar resolution was observed for development conditions producing ISO-A speeds ranging from 109 thru 423.

2. Extreme forced development (illustrated by the 192 second condition) produced slightly reduced resolution and contrast.

3. Extreme under development (illustrated by the 12 second condition) produced the same resolution as the baseline condition, but with greatly reduced contrast.

3412 Film

4. Optimum resolution is obtained when sensitometric response similar to the Open Skies sensitometric values are achieved.

5. Processing for increased contrast levels above the Open Skies level will not produce increases in film resolution, and may actually reduce film resolution.

SO-050 Film

6. Process conditions for SO-050 film can be varied from over development to under development as performed in this study, with no significant effect on film resolution.

Appendix

Contents For Each Film

Summary spread sheet for measured data

Sensitometric curves for each film through each process condition that were prepared using the Kodak 1B Sensitometer

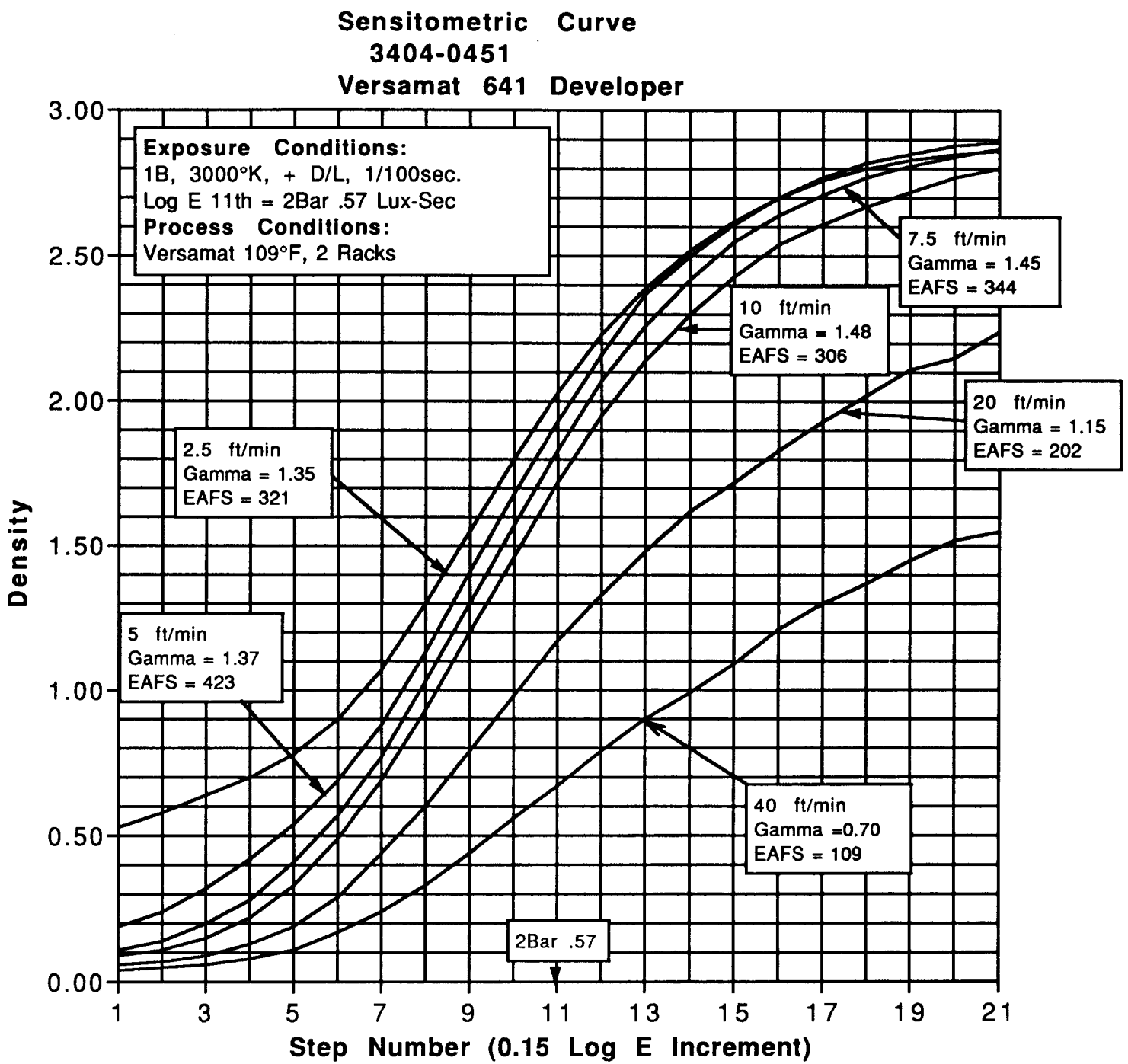
Resolution vs. ISO-A Gamma charts for each film

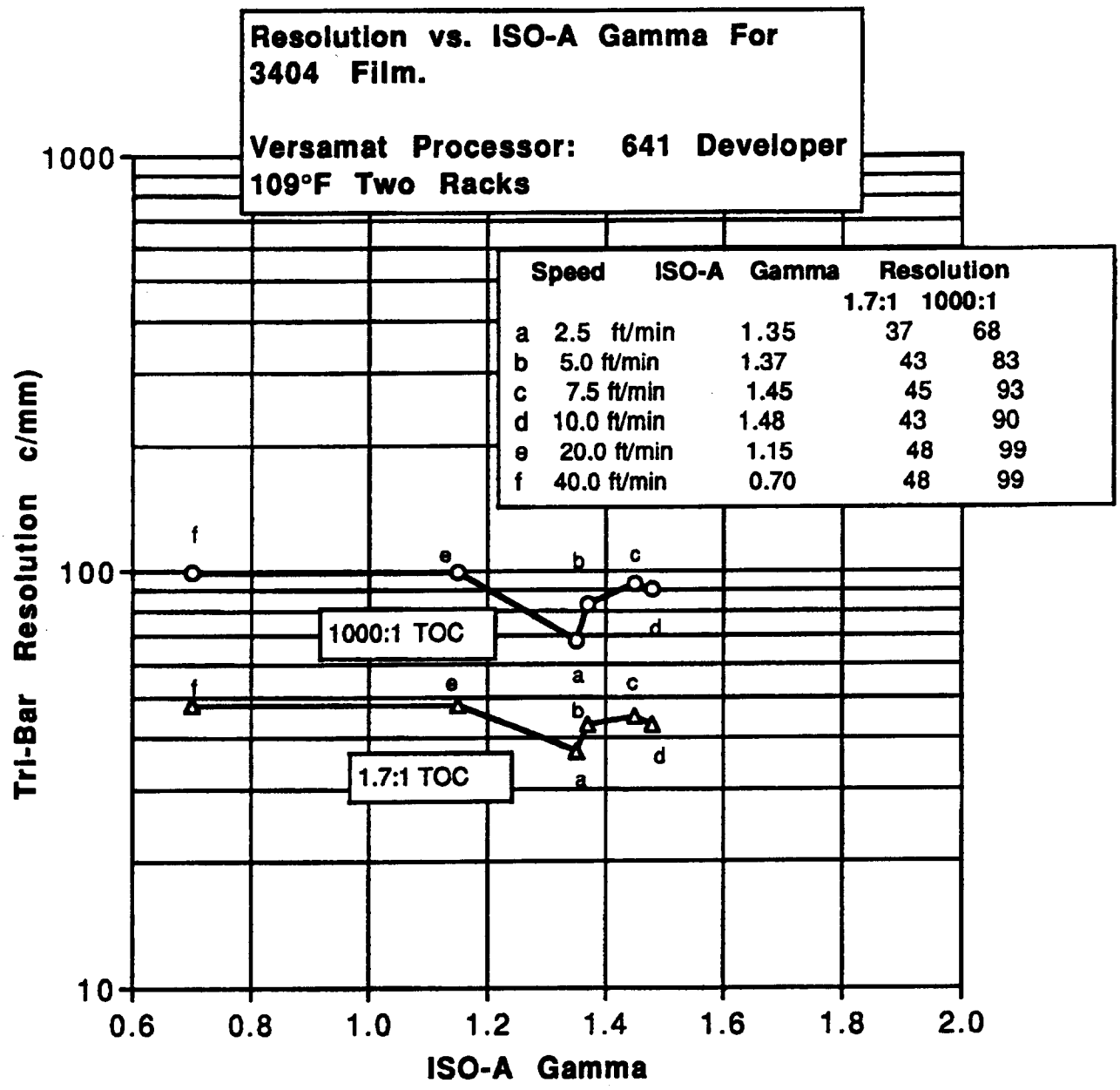
Resolution vs. Process Thruput Speed charts for each film

Resolution vs. Relative Log Exposure and Developed Density charts for each film and process condition

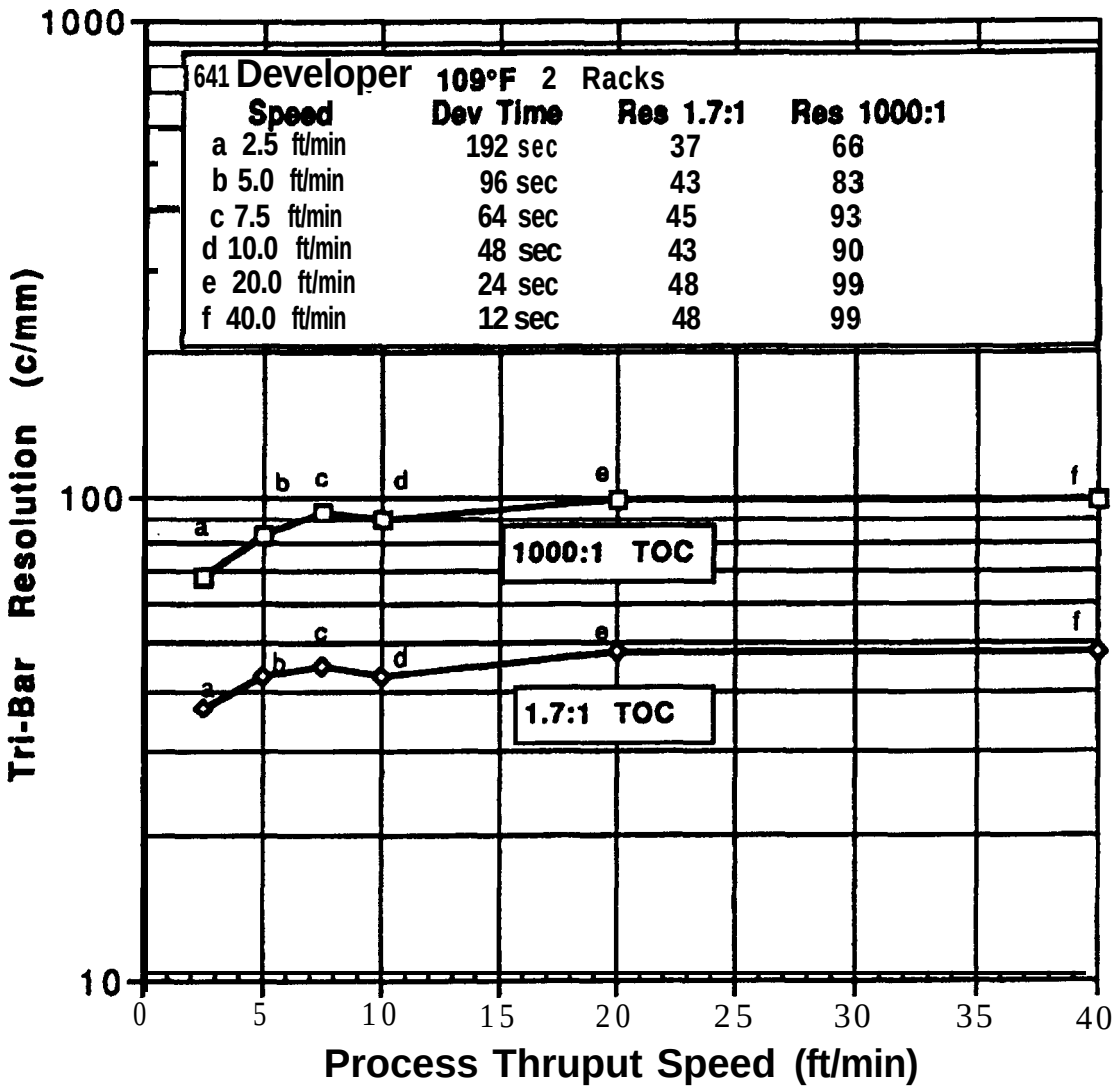
3404 Summary Data

	1	2	3	4	5	6	7	8	9
	Thruput Speed	ISO-A Speed	ISO-A Gamma	Hi Res	Lo Res	Log H Peak Hi	Log H Peak Lo	UK Hi Res	UK Lo Res
1	2.5	321	1.35	68	37	-2.33	-2.48	68	37
2	5	423	1.37	83	43	-1.9	-2.07	85	44
3	7.5	344	1.45	93	45	-2.11	-2.11	90	48
4	10	306	1.48	90	43	-2.1	-1.9	98	45
5	20	202	1.15	99	48	-1.95	-1.85	90	43
6	40	109	0.70	99	48	-1.23	-1.43	80	26
7									
8									
9									
10									
11									
12									


Sensitometric Curve
3404-0451
Versamat 641 Developer
Exposure Conditions:
1B, 3000°K, + D/L, 1/100sec.
Log E 11th = 2Bar .57 Lux-Sec
Process Conditions:
Versamat 109°F, 2 Racks
7.5 ft/min
Gamma = 1.45
EAFS = 344
10 ft/min
Gamma = 1.48
EAFS = 306
20 ft/min
Gamma = 1.15
EAFS = 202
2.5 ft/min
Gamma = 1.35
EAFS = 321
5 ft/min
Gamma = 1.37
EAFS = 423
40 ft/min
Gamma =0.70
EAFS = 109
2Bar .57
Density
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
3
5
7
9
11
13
15
17
19
21
Step Number (0.15 Log E Increment)

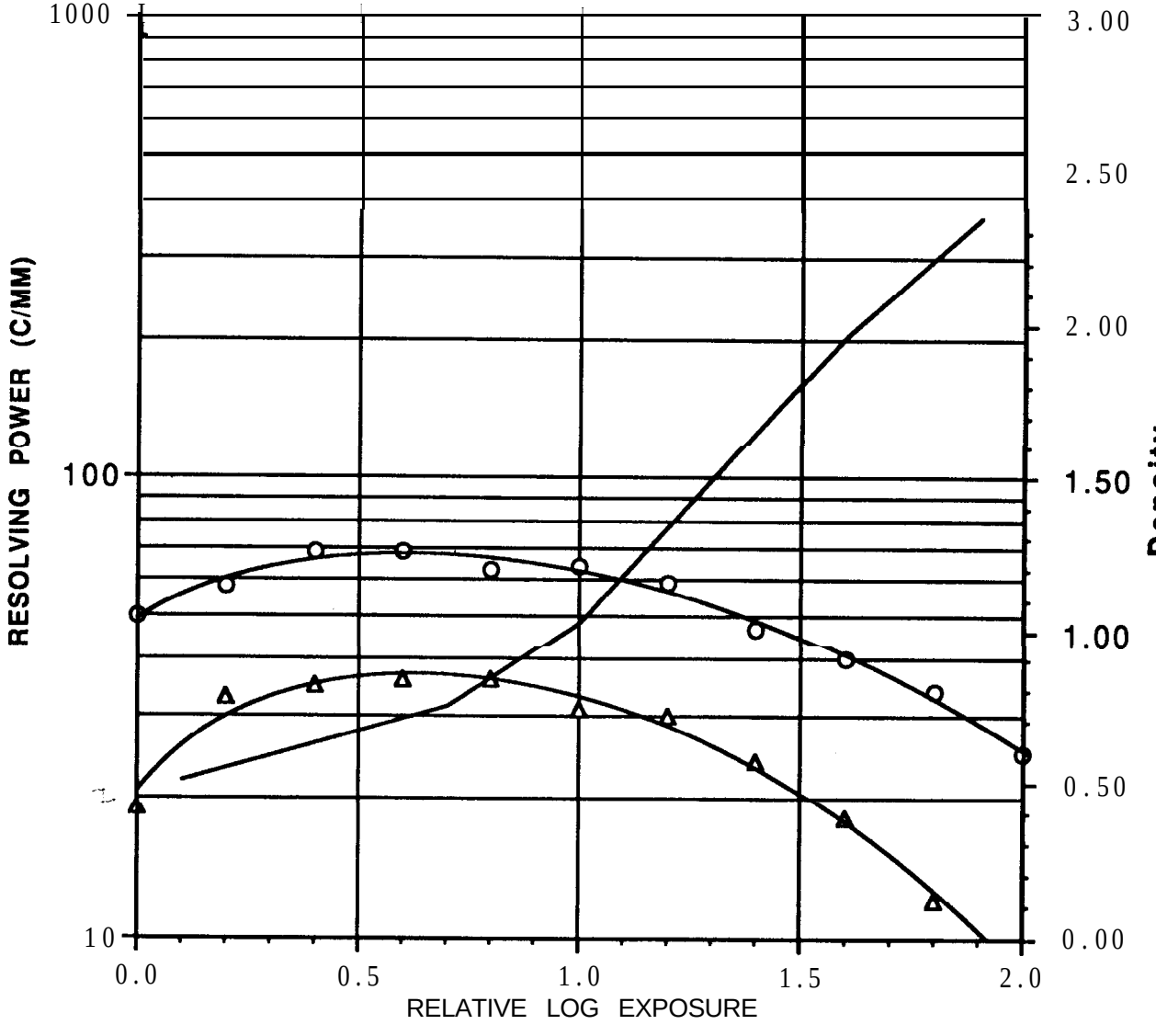

Resolution vs. ISO-A Gamma For 3404 Film.
Versamat Processor: 641 Developer 109°F Two Racks
Speed ISO-A Gamma Resolution 1.7:1 1000:1
a 2.5 ft/min 1.35 37 68
b 5.0 ft/min 1.37 43 83
c 7.5 ft/min 1.45 45 93
d 10.0 ft/min 1.48 43 90
e 20.0 ft/min 1.15 48 99
f 40.0 ft/min 0.70 48 99
1000:1 TOC
1.7:1 TOC
Tri-Bar Resolution c/mm)
1000
100
10
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ISO-A Gamma

Resolution vs. Process Thruput Speed
Versamat Processor: 641 Developer
Two Racks in Developer Section
3404 **Film**



VERSAMAT 1140
641 DEVELOPER
2.5 fpm, 109°F
2 RACKS

3404-0451



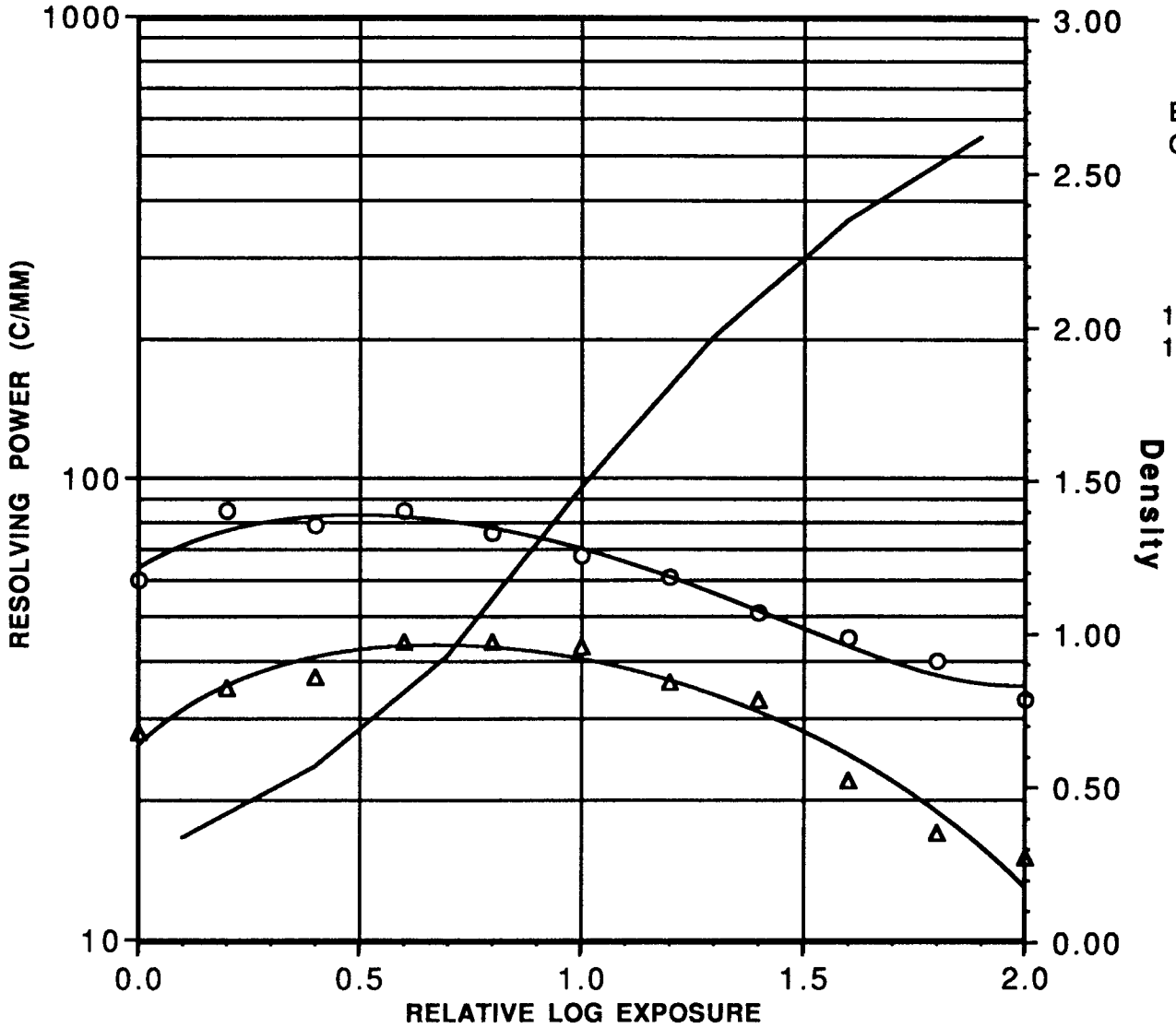
EAFS = 321
Gamma = 1.35

PEAK RESOLUTION
1000:1 TOC 68 C/MM ± 12
1.70:1 TOC 37 C/MM ± 12

RESOLVING POWER ± VALUES ARE AVERAGE OF ± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-I
LOG # 95033F

VERSAMAT 1140
641 DEVELOPER
5 fpm, 109°F
2 RACKS



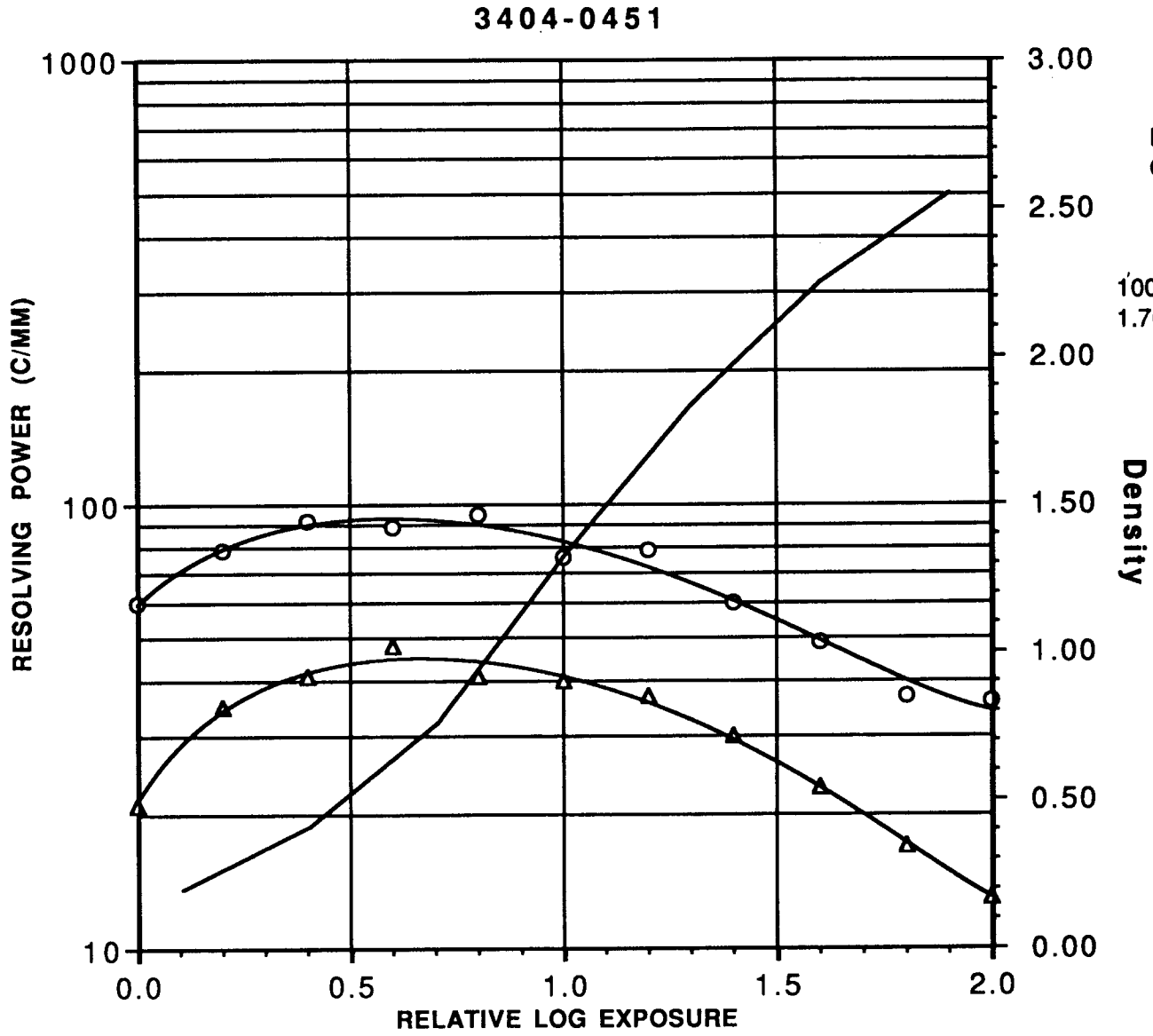
EAFS = 423
Gamma = 1.37

PEAK RESOLUTIION
1000:1 TOC 83 C/MM ± 12
1.70:1 TOC 43 C/MM ± 7

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-1
LOG # 95033E

VERSAMAT 1140
641 DEVELOPER
7.5 fpm, 109°F
2 RACKS



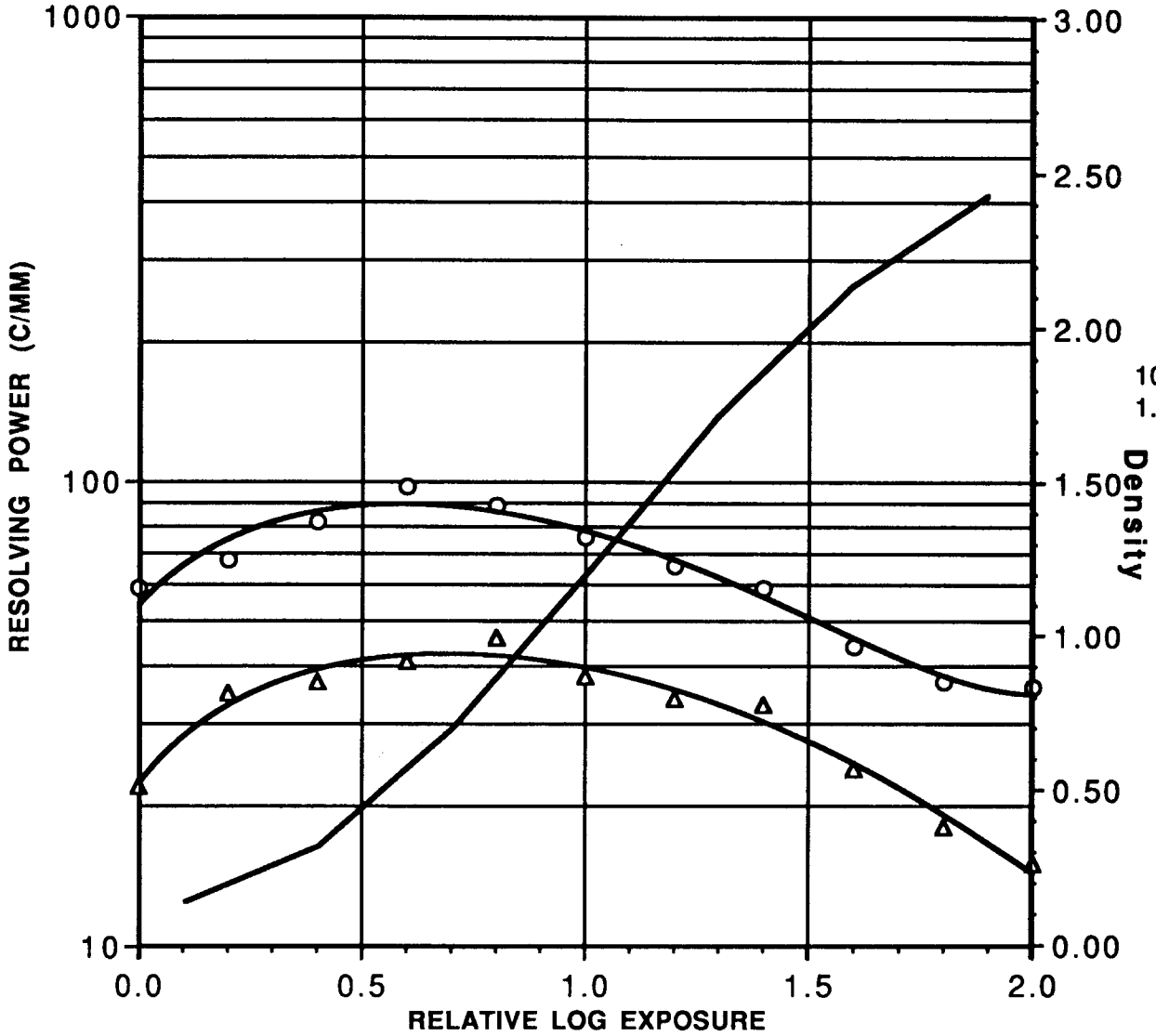
EAFS = 344
Gamma = 1.45

PEAK RESOLUTIION
1000:1 TOC 93 C/MM ± 13
1.70:1 TOC 45 C/MM ± 5

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-1
LOG # 95033D

3404-0451



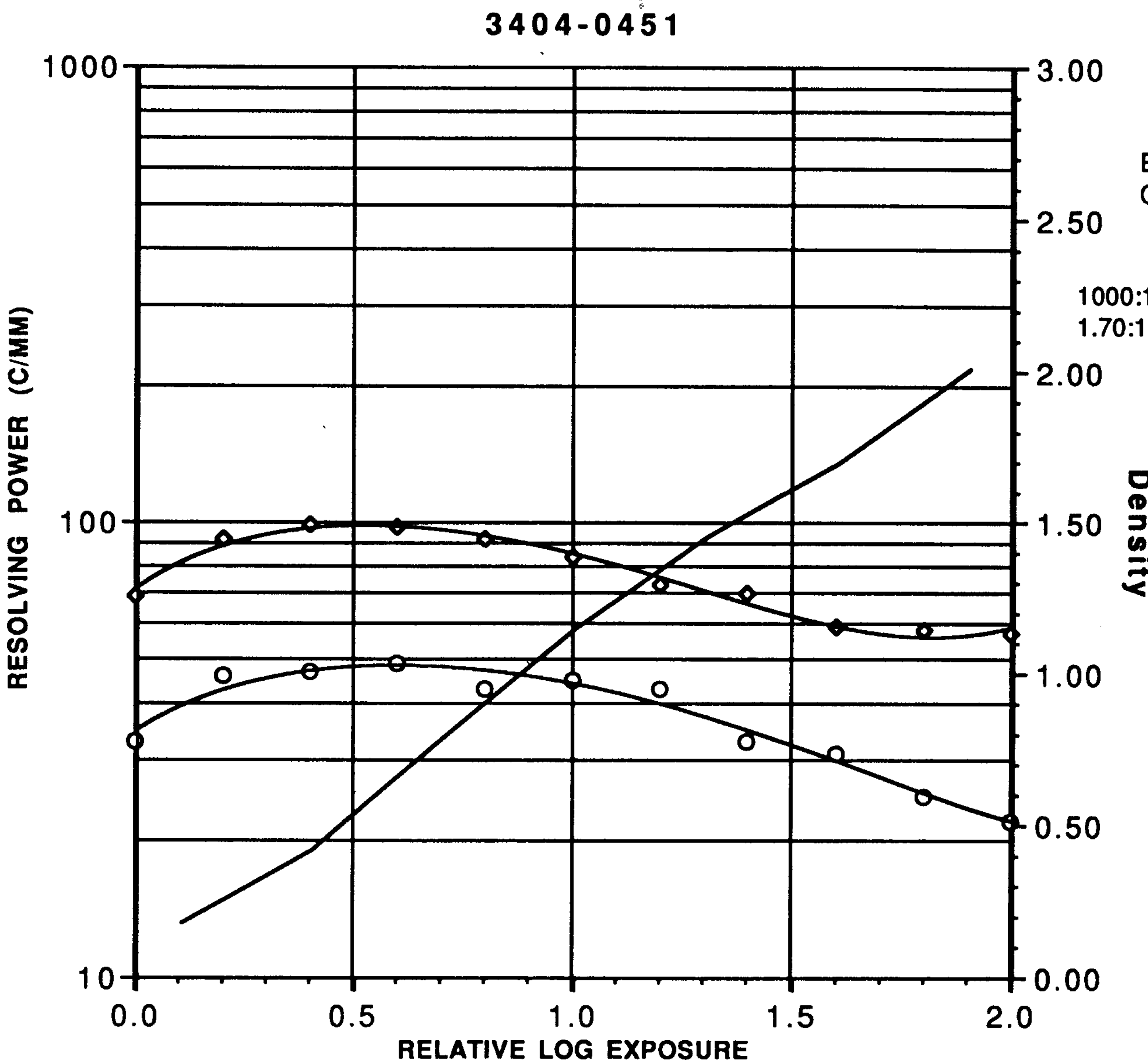
VERSAMAT 1140
641 DEVELOPER
10 fpm, 109°F
2 RACKS

EAFS = 306
Gamma = 1.48

PEAK RESOLUTION
1000:1 TOC 90 C/MM ± 17
1.70:1 TOC 43 C/MM ± 10

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-1
LOG # 95033A



VERSAMAT 1140
641 DEVELOPER
20 fpm, 109°F
2 RACKS

EAFS = 202
Gamma = 1.15

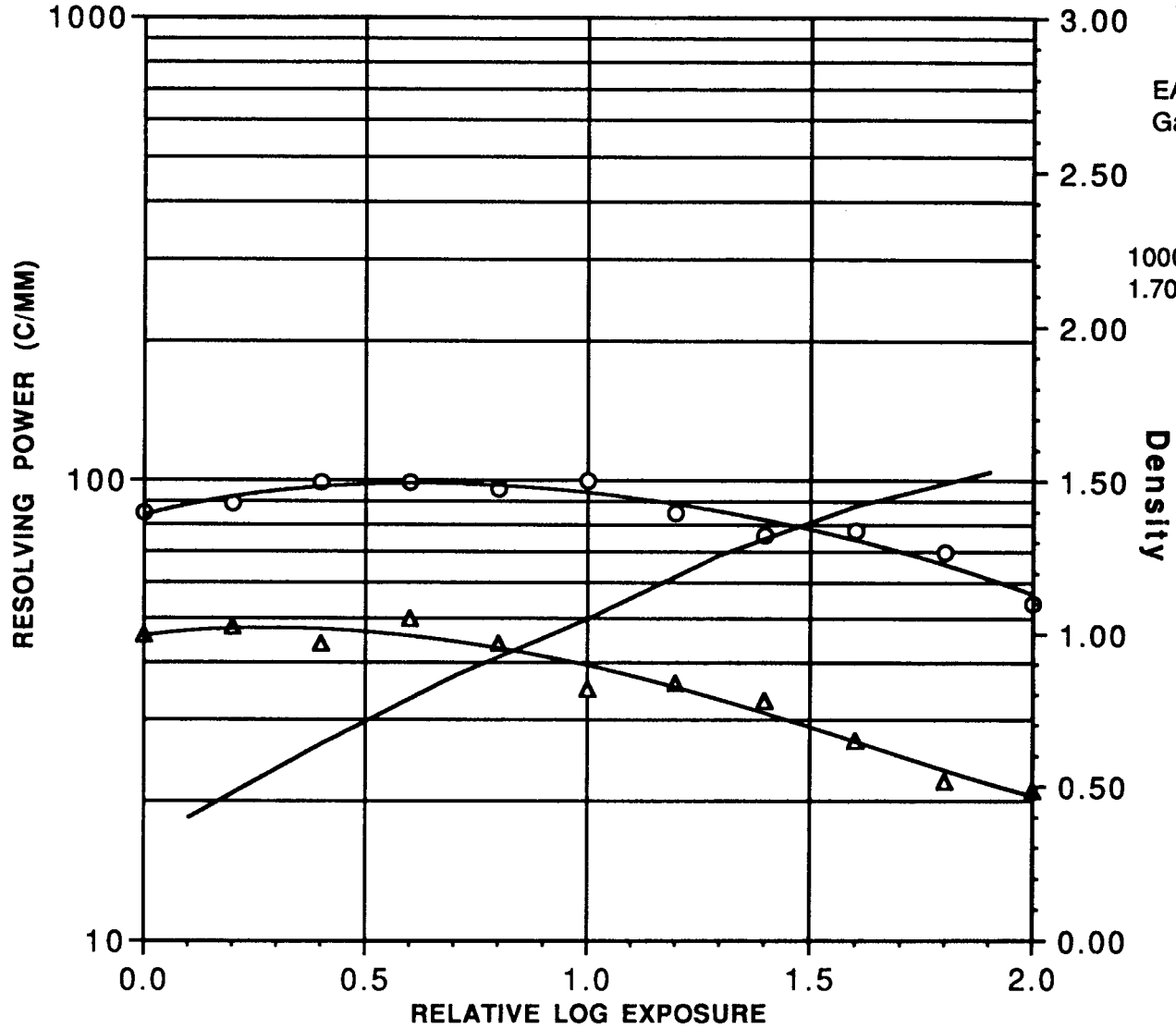
PEAK RESOLUTIION
1000:1 TOC 99 C/MM ± 11
1.70:1 TOC 48 C/MM ± 5

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-1
LOG # 95033C

VERSAMAT 1140
641 DEVELOPER
40 fpm, 109°F
2 RACKS

3404-0451



EAFS = 109
Gamma = 0.70

PEAK RESOLUTION
1000:1 TOC 99 C/MM ± 19
1.70:1 TOC 48 C/MM ± 4

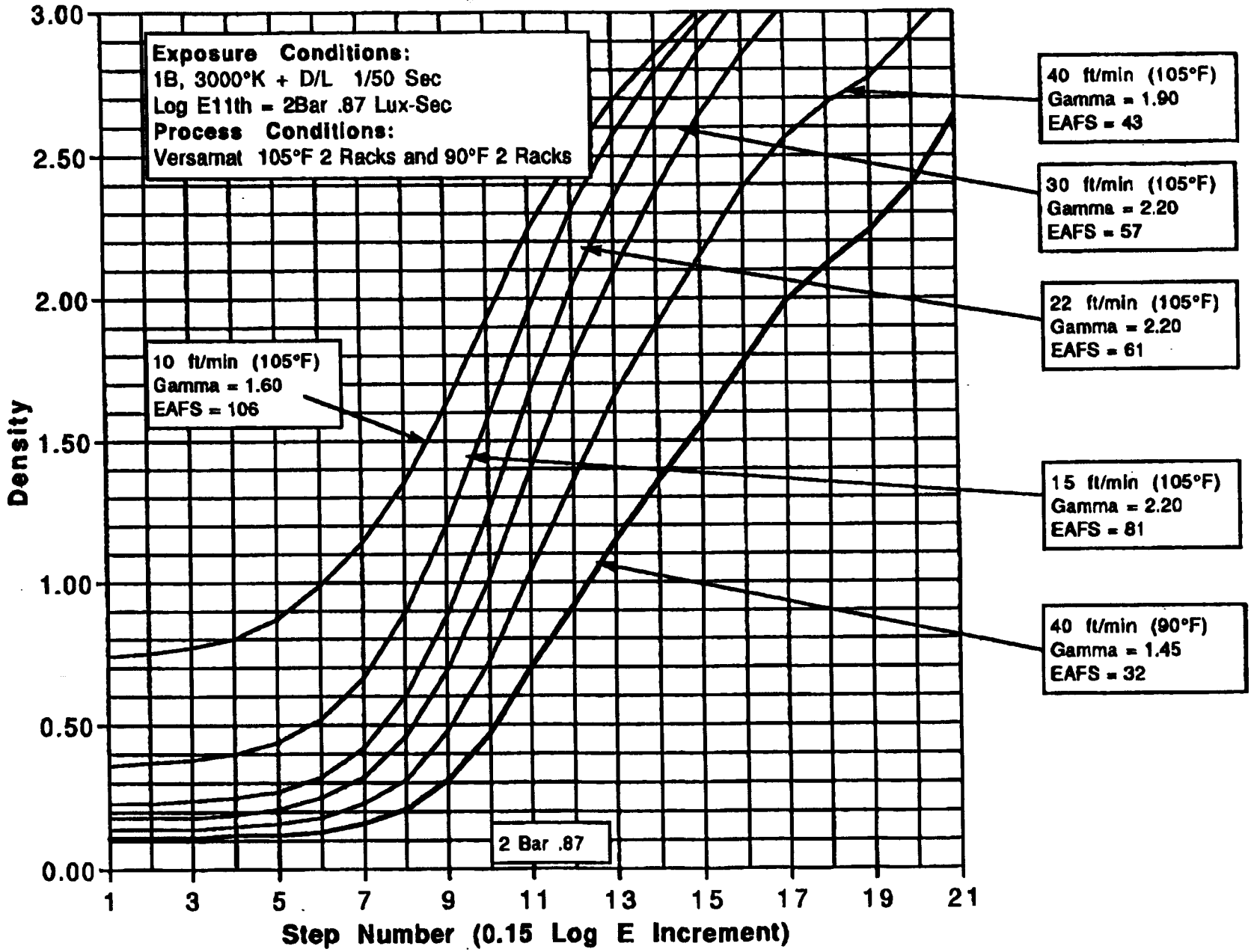
RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

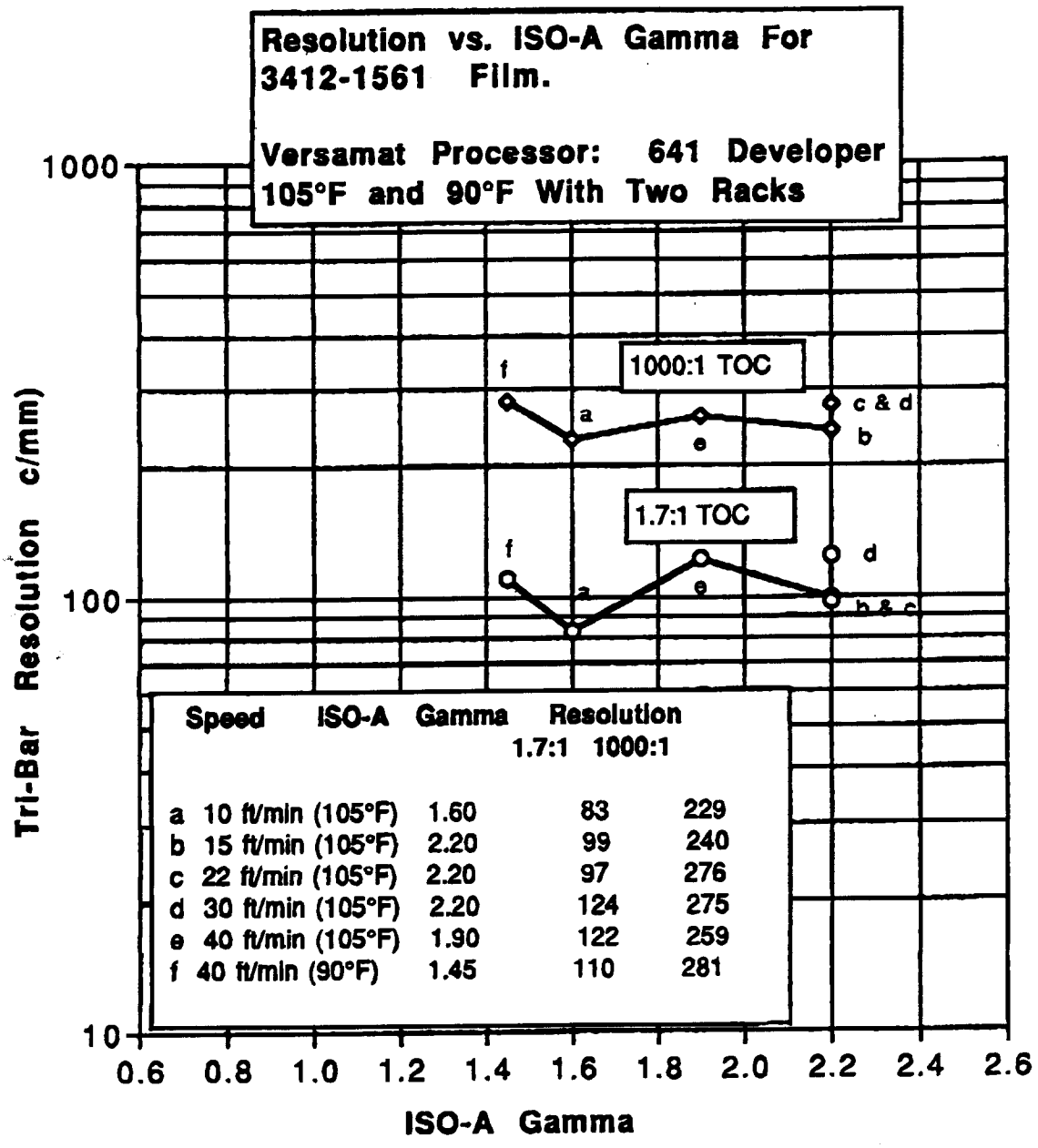
M&P # 091895-1
LOG # 95033B

3412 Summary Data

	1	2	3	4	5	6	7	8
	Process Temp	Thruput Speed	ISO-A Speed	ISO-A Gamma	Hi Res	Lo Res	Hi Res Log E	Lo Res Log E
1	105F	10	106	1.60	229	83	-1.61	-1.61
2	105F	15	81	2.20	240	99	-1.65	-1.65
3	105F	22	61	2.20	276	97	-1.54	-1.54
4	105F	30	57	2.20	275	124	-1.43	-1.5
5	105F	40	43	1.90	259	122	-1.17	-1.38
6	90F	40	32	1.45	281	110	-2.82	-2.82

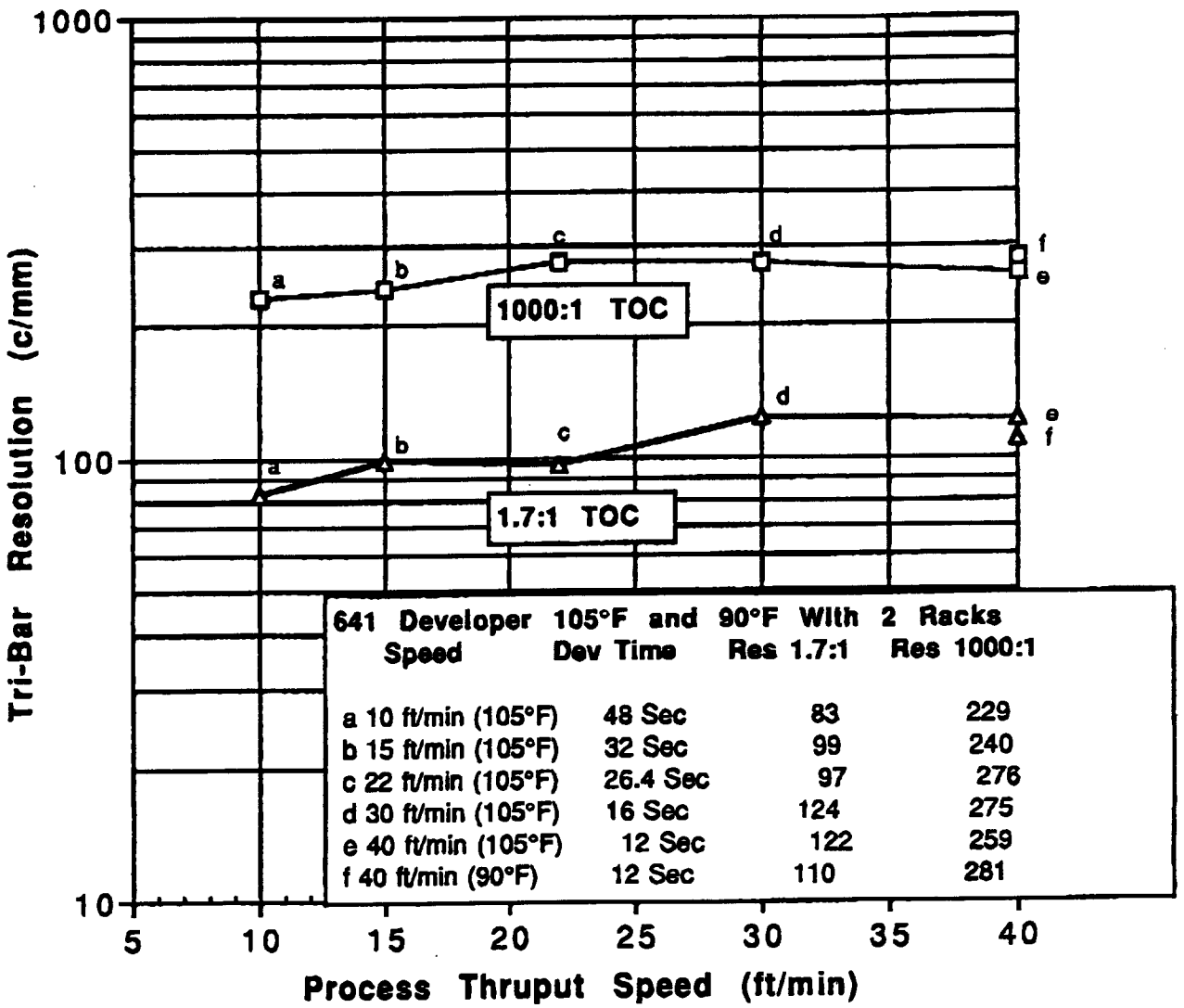
Sensitometric Curves
3412-1561
Versamat 641 Developer





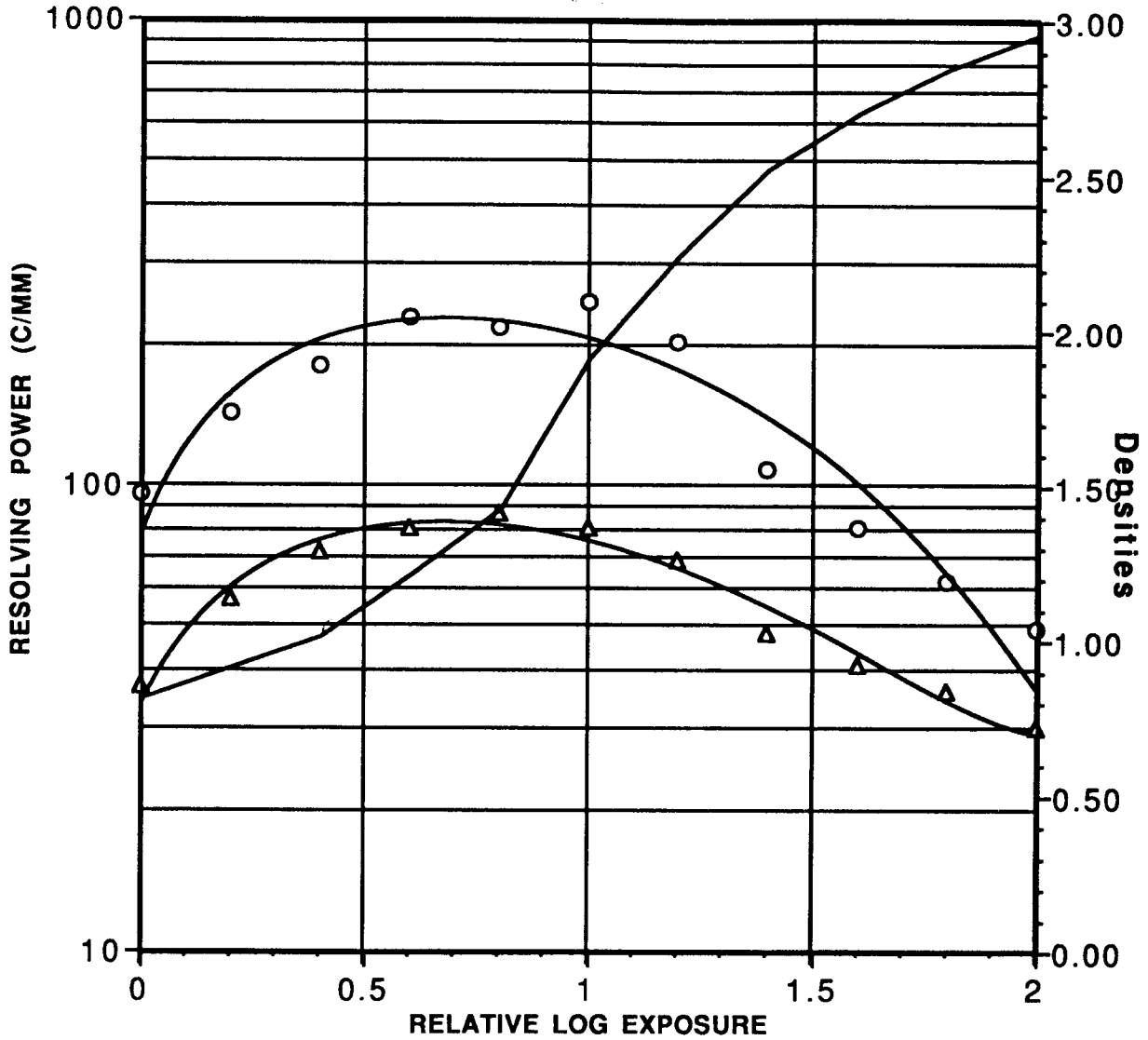
Speed	ISO-A Gamma	Resolution 1.7:1	Resolution 1000:1
a 10 ft/min (105°F)	1.60	83	229
b 15 ft/min (105°F)	2.20	99	240
c 22 ft/min (105°F)	2.20	97	276
d 30 ft/min (105°F)	2.20	124	275
e 40 ft/min (105°F)	1.90	122	259
f 40 ft/min (90°F)	1.45	110	281

Resolution vs. Process Thruput Speed
Versamat Processor: 641 Developer
Two Racks in Developer Section
3412-1561 Film



641 Developer 105°F and 90°F With 2 Racks			
Speed	Dev Time	Res 1.7:1	Res 1000:1
a 10 ft/min (105°F)	48 Sec	83	229
b 15 ft/min (105°F)	32 Sec	99	240
c 22 ft/min (105°F)	26.4 Sec	97	276
d 30 ft/min (105°F)	16 Sec	124	275
e 40 ft/min (105°F)	12 Sec	122	259
f 40 ft/min (90°F)	12 Sec	110	281

3412-1561



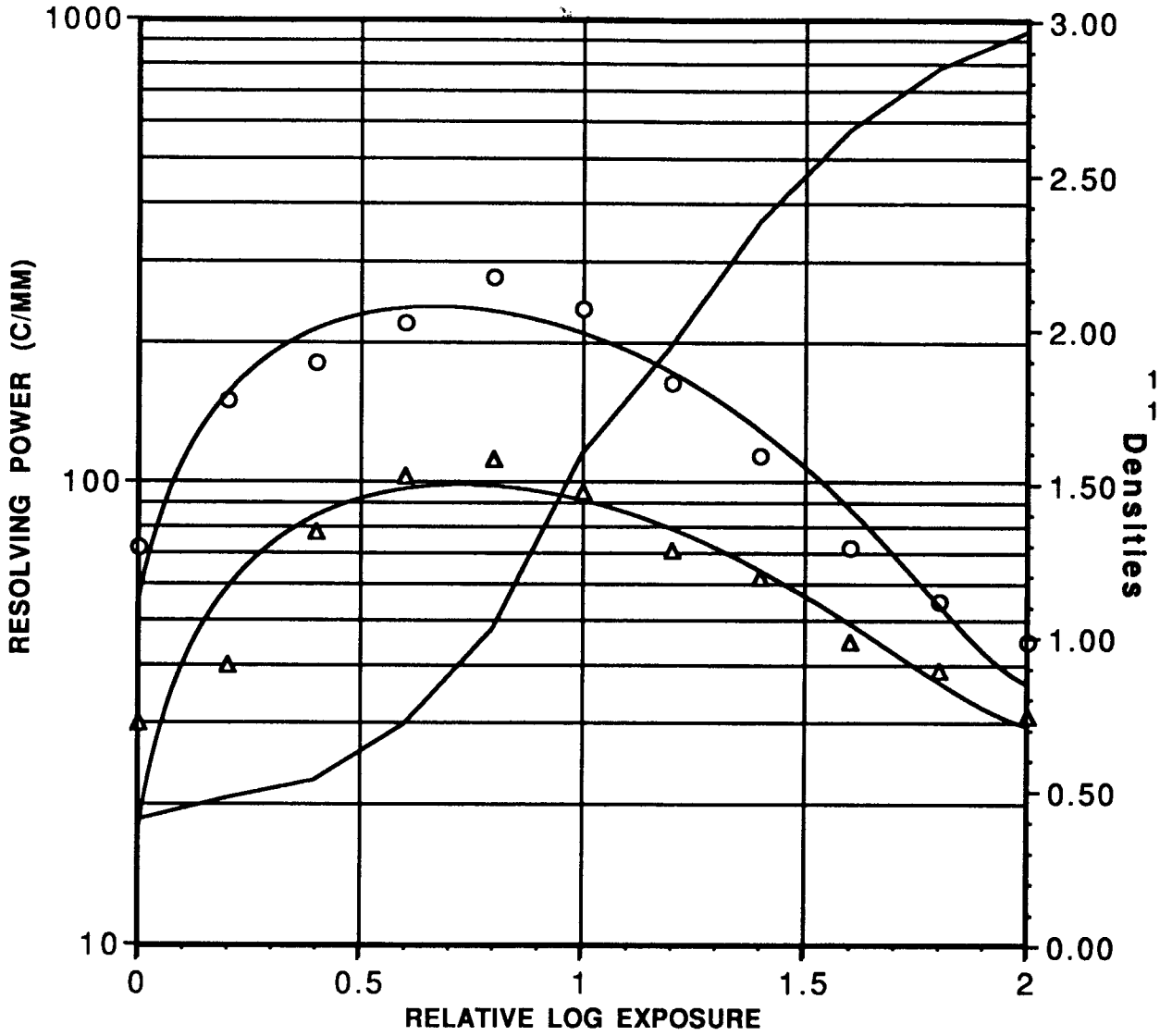
VERSAMAT 1140
641 DEVELOPER
105° 10 FPM

PEAK RESOLUTION
1000:1 TOC 229 C/MM ± 56
1.70:1 TOC 83 C/MM ± 11

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-2
LOG # 95034E

3412-1561



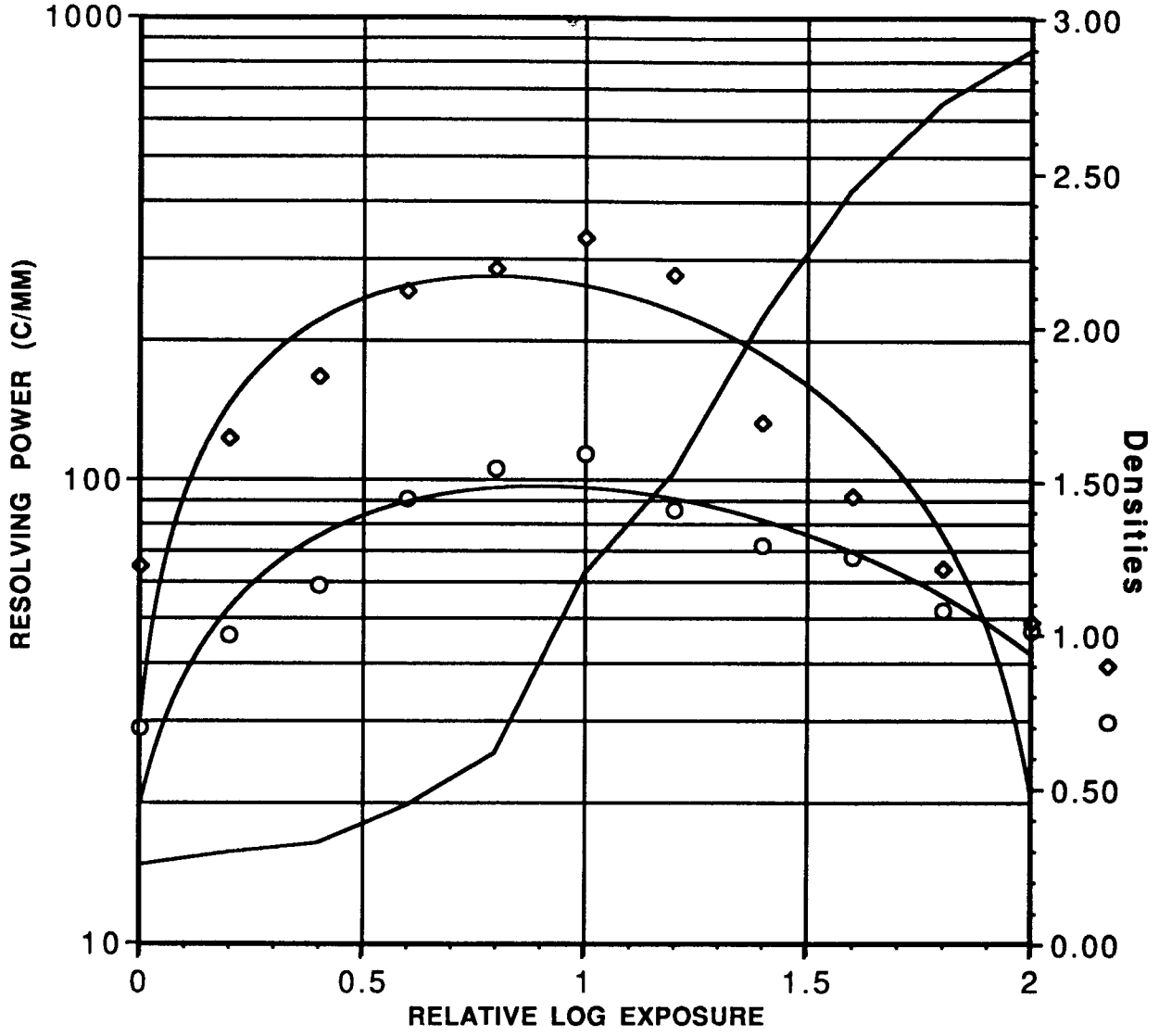
VERSAMAT 1140
641 DEVELOPER
105° 15 FPM

PEAK RESOLUTION
1000:1 TOC 240 C/MM ± 57
1.70:1 TOC 99 C/MM ± 31

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-2
LOG # 95034D

3412-1561



VERSAMAT 1140
641 DEVELOPER
105° 22 FPM

PEAK RESOLUTION
1000:1 TOC 276 C/MM ± 3
1.70:1 TOC 97 C/MM ± 27

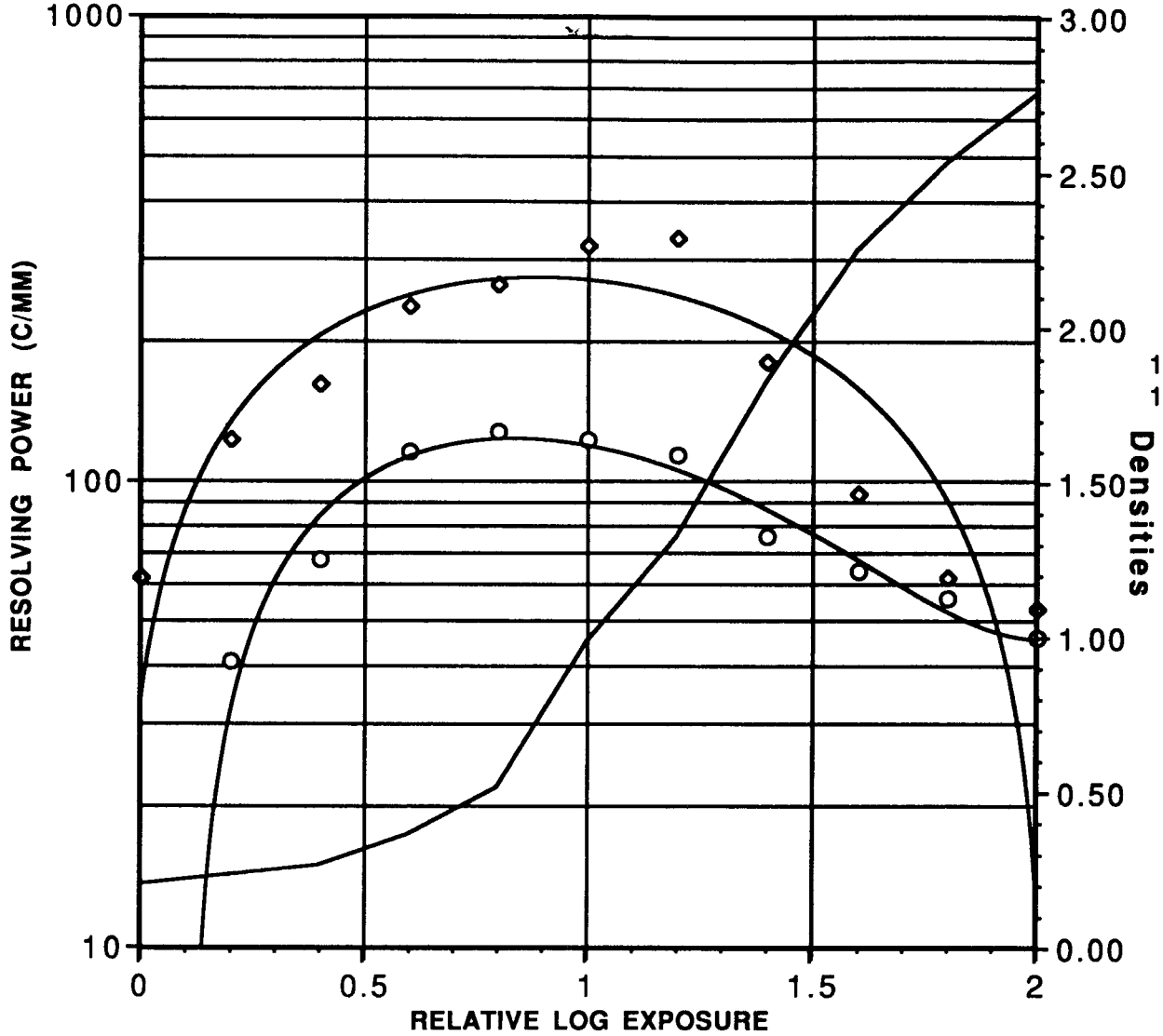
◇ 1000:1

○ 1.70:1

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-2
LOG # 95034A

3412-1561



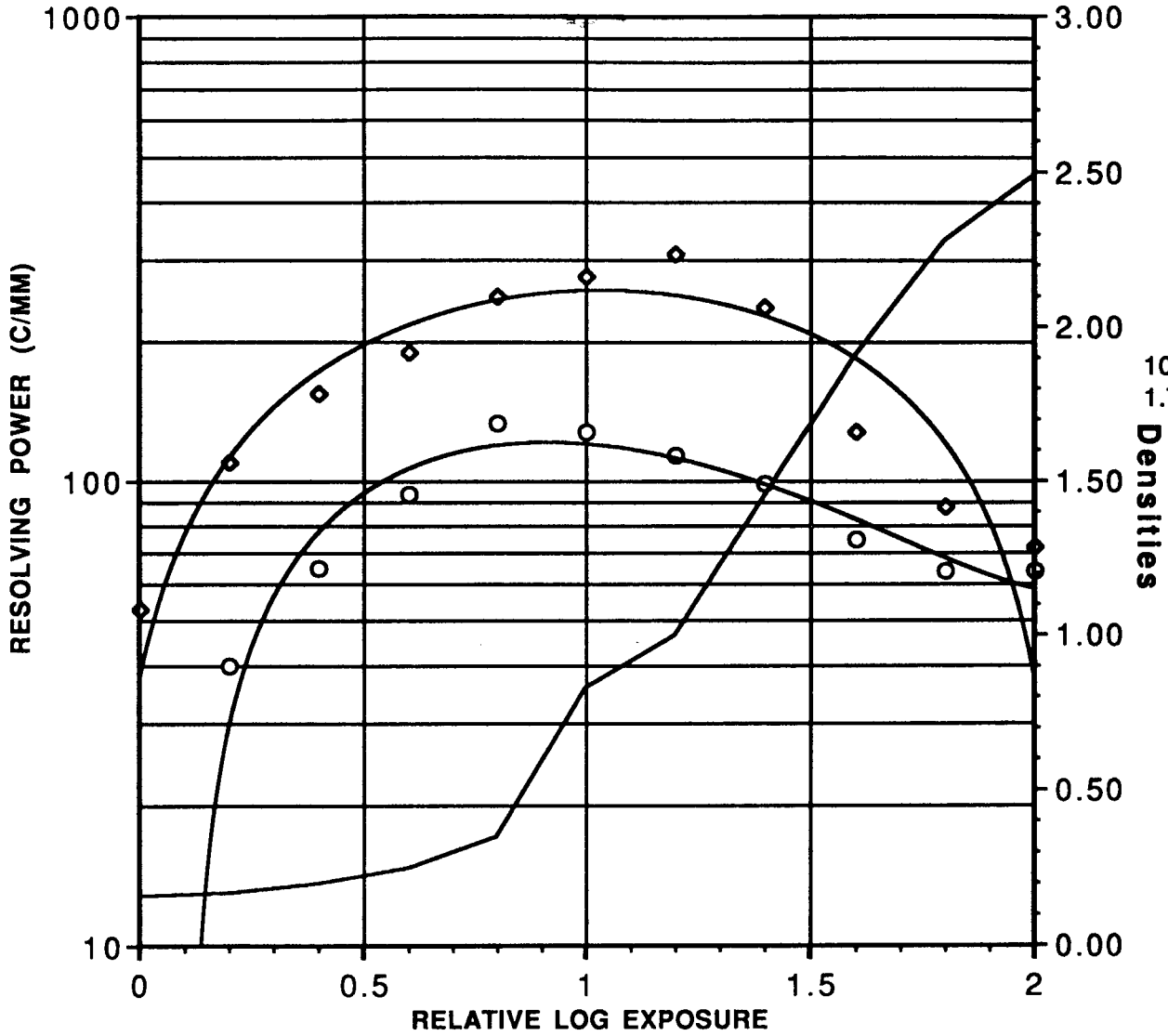
VERSAMAT 1140
641 DEVELOPER
105° 30 FPM

PEAK RESOLUTION
1000:1 TOC 275 C/MM ± 54
1.70:1 TOC 124 C/MM ± 27

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-2
LOG # 95034C

3412-1561

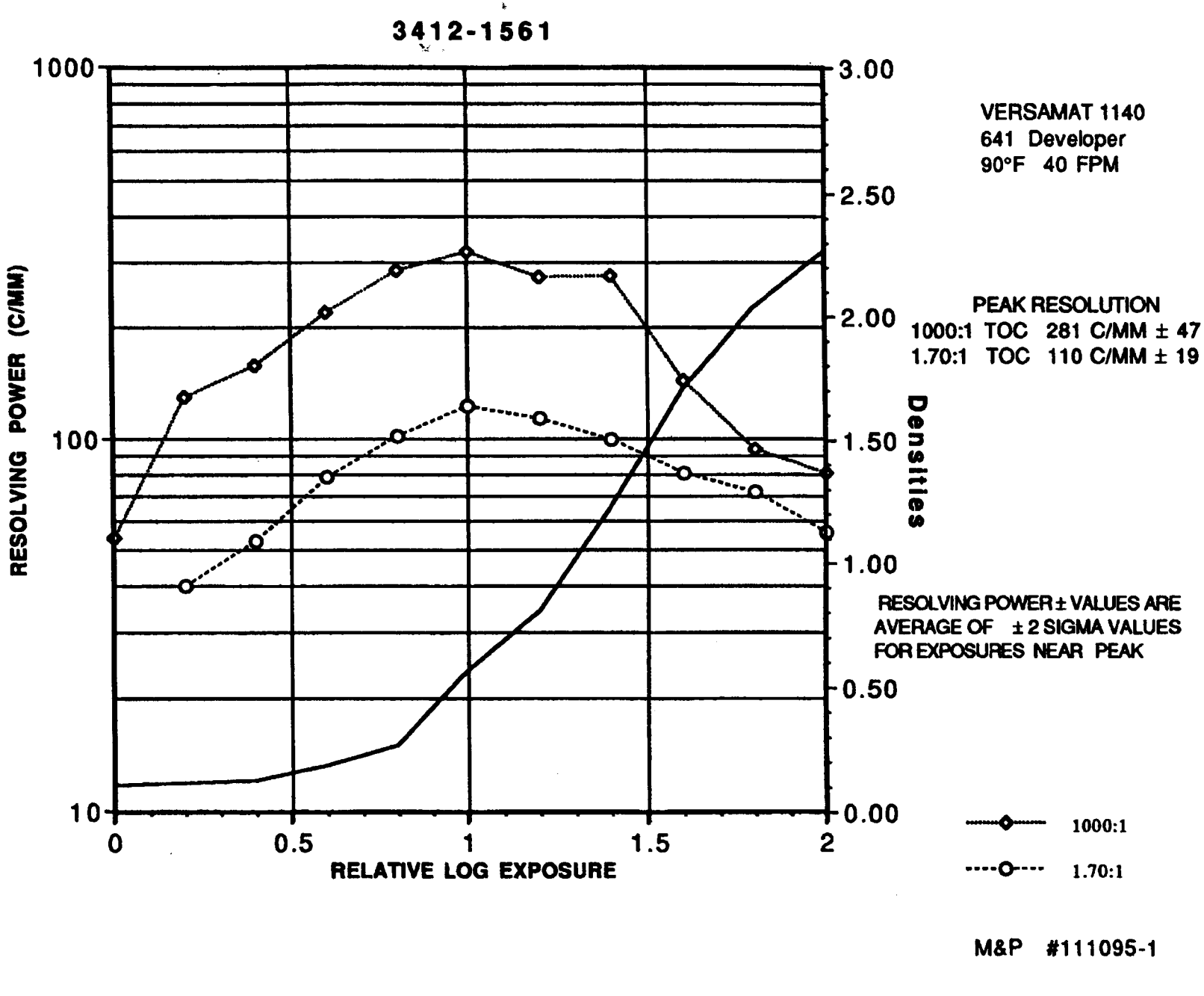


VERSAMAT 1140
641 DEVELOPER
105° 40 FPM

PEAK RESOLUTION
1000:1 TOC 259 C/MM ± 67
1.70:1 TOC 122 C/MM ± 23

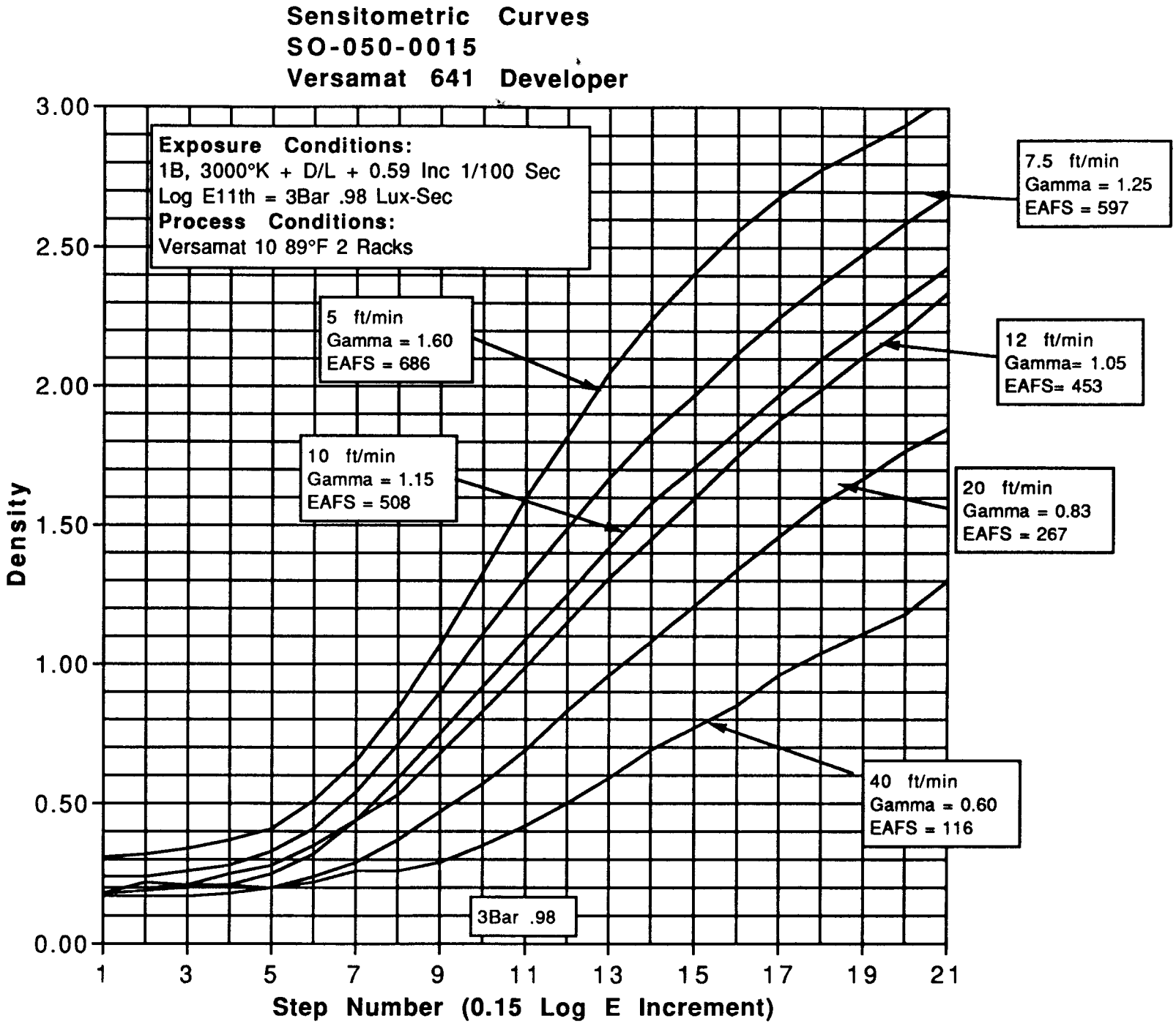
RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

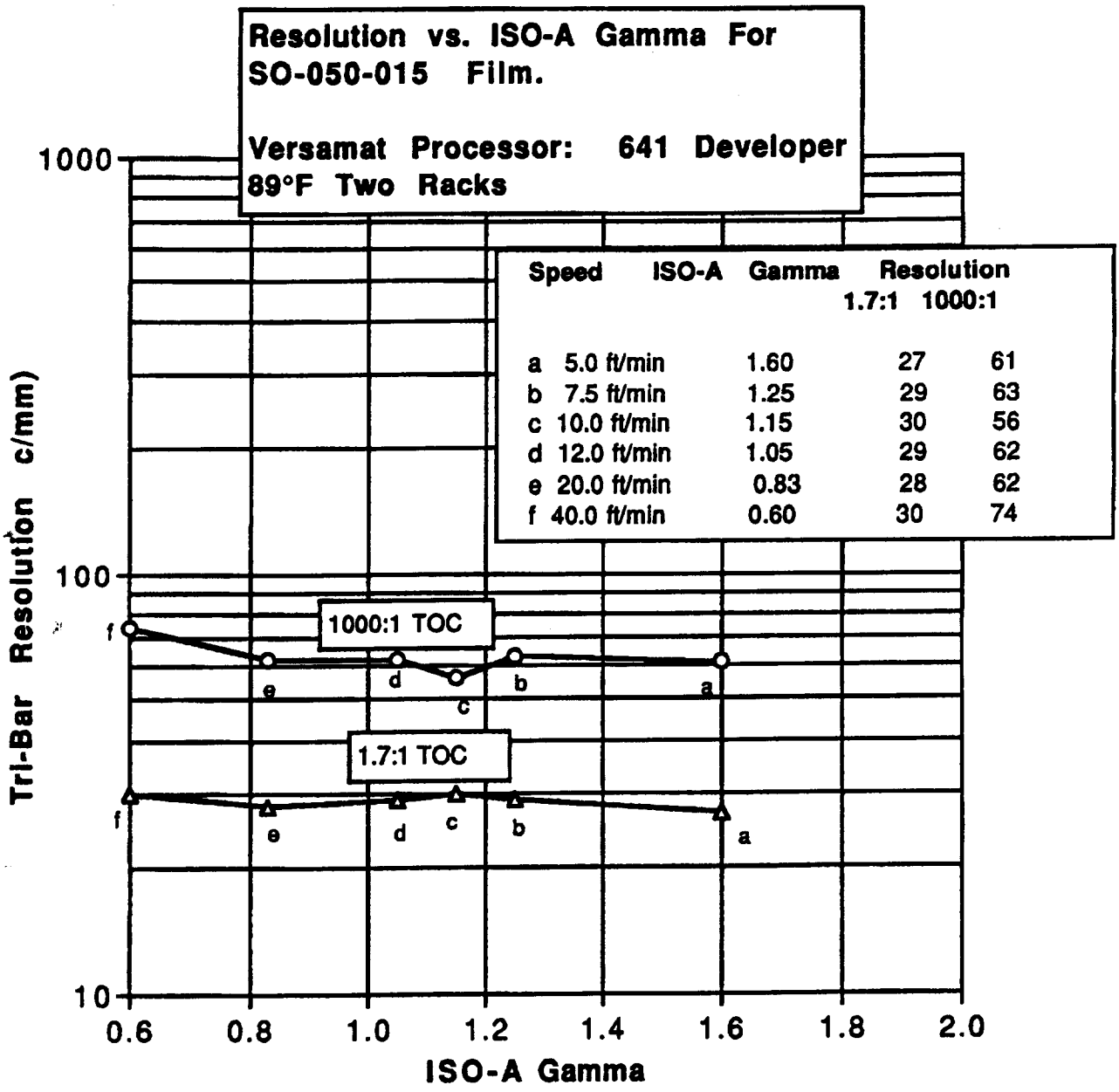
M&P # 091895-2
LOG # 95034B


3412-1561
1000
100
10
RESOLVING POWER (C/MM)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Densities
0
0.5
1
1.5
2
RELATIVE LOG EXPOSURE
VERSAMAT 1140
641 Developer
90°F 40 FPM
PEAK RESOLUTION
1000:1 TOC 281 C/MM ± 47
1.70:1 TOC 110 C/MM ± 19
RESOLVING POWER ± VALUES ARE
AVERAGE OF ± 2 SIGMA VALUES
FOR EXPOSURES NEAR PEAK
1000:1
1.70:1
M&P #111095-1

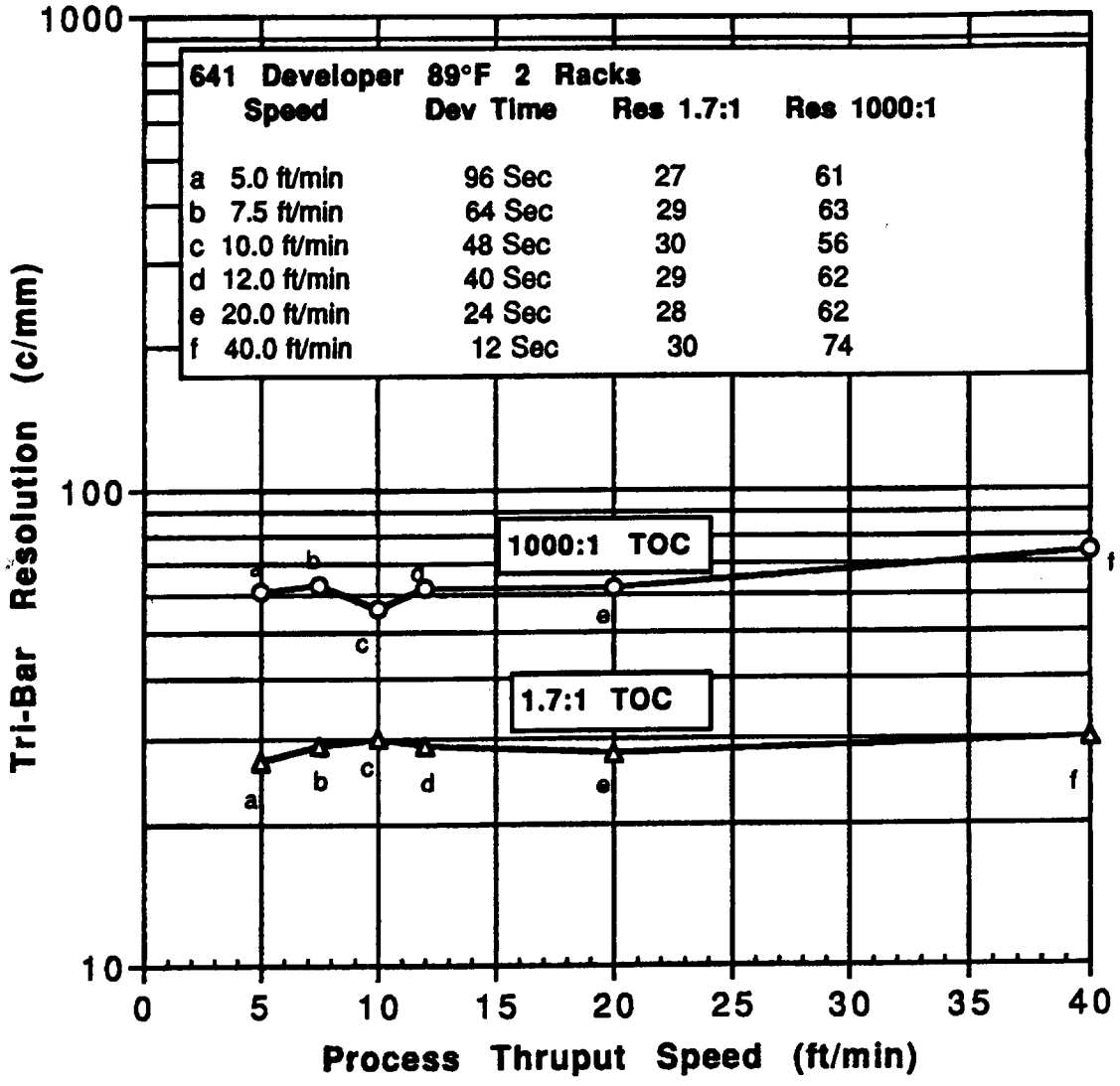
SO-050 Summary Data

	1	2	3	4	5	6	7
	Thruput Speed	ISO-A Speed	ISO-A Gamma	Hi Res	Lo Res	Log H Hi Res	Log H Lo Res
1	5	686	1.60	61	27	-2.25	-2.25
2	7.5	597	1.25	63	29	-2.25	-2.25
3	10	508	1.15	56	30	-2.36	-2.36
4	12	453	1.05	62	29	-2.3	-2.1
5	20	267	0.83	62	28	-2.07	-2.07
6	40	116	0.60	74	30	-1.64	-1.64
7							
8							
9							
10							


Sensitometric Curves
SO-050-0015
Versamat 641 Developer
Exposure Conditions:
1B, 3000°K + D/L + 0.59 Inc 1/100 Sec
Log E11th = 3Bar .98 Lux-Sec
Process Conditions:
Versamat 10 89°F 2 Racks
7.5 ft/min
Gamma = 1.25
EAFS = 597
5 ft/min
Gamma = 1.60
EAFS = 686
12 ft/min
Gamma= 1.05
EAFS= 453
10 ft/min
Gamma = 1.15
EAFS = 508
20 ft/min
Gamma = 0.83
EAFS = 267
40 ft/min
Gamma = 0.60
EAFS = 116
3Bar .98
Density
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
3
5
7
9
11
13
15
17
19
21
Step Number (0.15 Log E Increment)

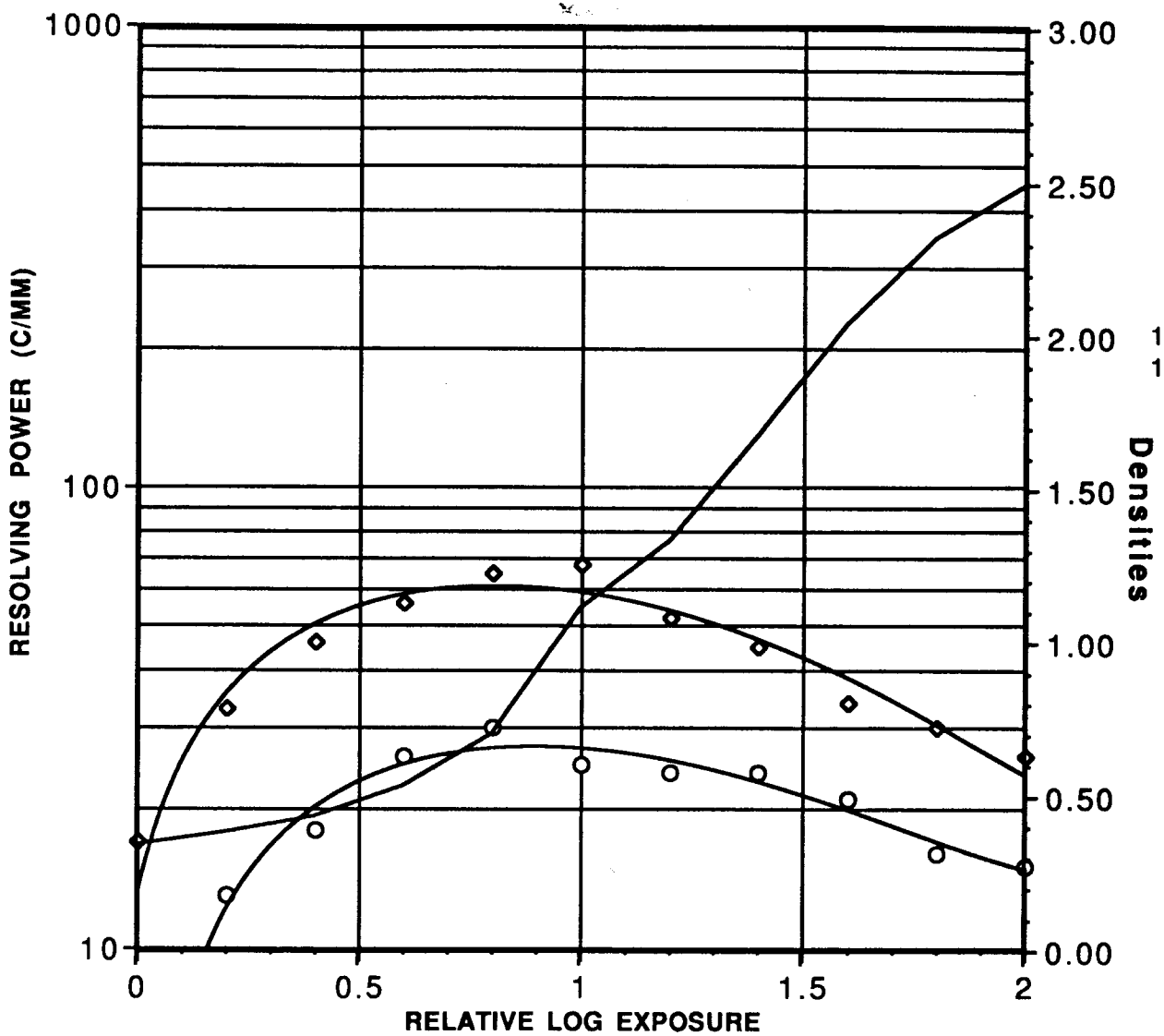

Resolution vs. ISO-A Gamma For SO-050-015 Film.
Versamat Processor: 641 Developer 89°F Two Racks
Speed ISO-A Gamma Resolution 1.7:1 1000:1
a 5.0 ft/min 1.60 27 61
b 7.5 ft/min 1.25 29 63
c 10.0 ft/min 1.15 30 56
d 12.0 ft/min 1.05 29 62
e 20.0 ft/min 0.83 28 62
f 40.0 ft/min 0.60 30 74
1000
100
10
Tri-Bar Resolution c/mm)
1000:1 TOC
1.7:1 TOC
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ISO-A Gamma

Resolution vs. Process Thruput Speed
Versamat Processor: 641 Developer
Two Racks in Developer Section
SO-050-015 Film



SO-050-0015

VERSAMAT 1140
641 DEVELOPER
89° 5 FPM

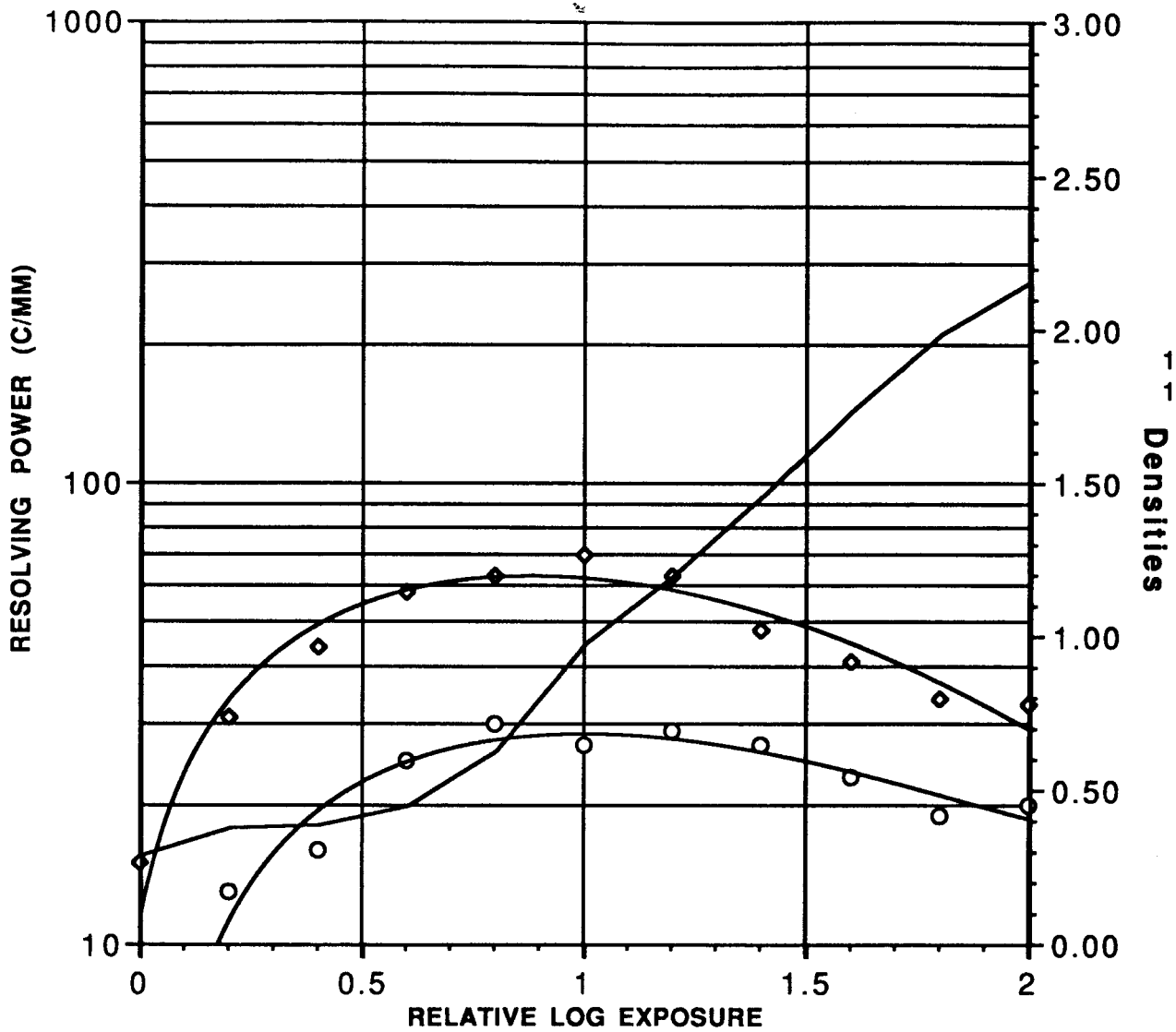


PEAK RESOLUTION
1000:1 TOC 61 C/MM ± 8
1.70:1 TOC 27 C/MM ± 5

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-3
LOG # 95035F

SO-050-0015

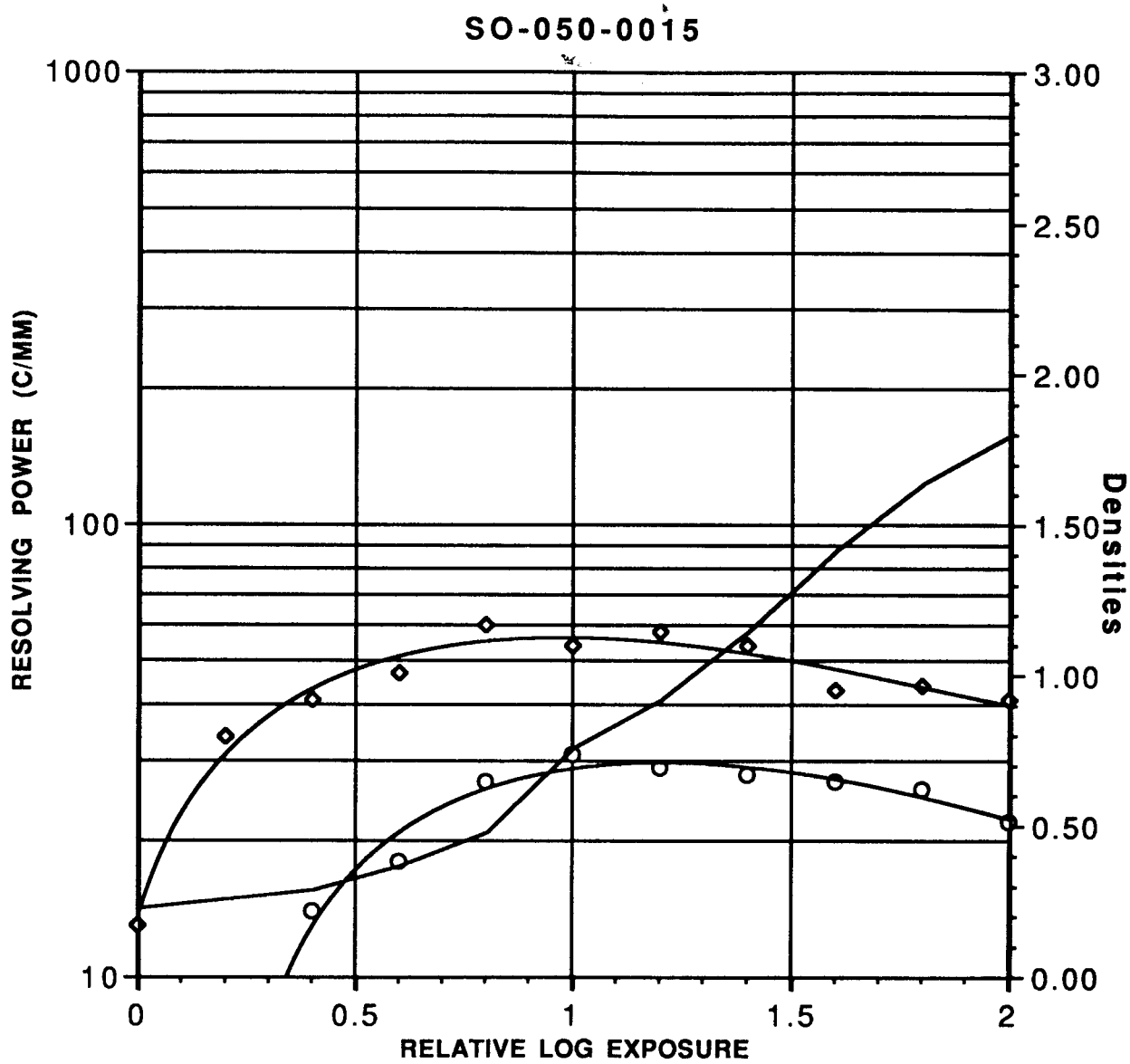


VERSAMAT 1140
641 DEVELOPER
89° 7.5 FPM

PEAK RESOLUTION
1000:1 TOC 63 C/MM ± 12
1.70:1 TOC 29 C/MM ± 6

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-3
LOG # 95035E



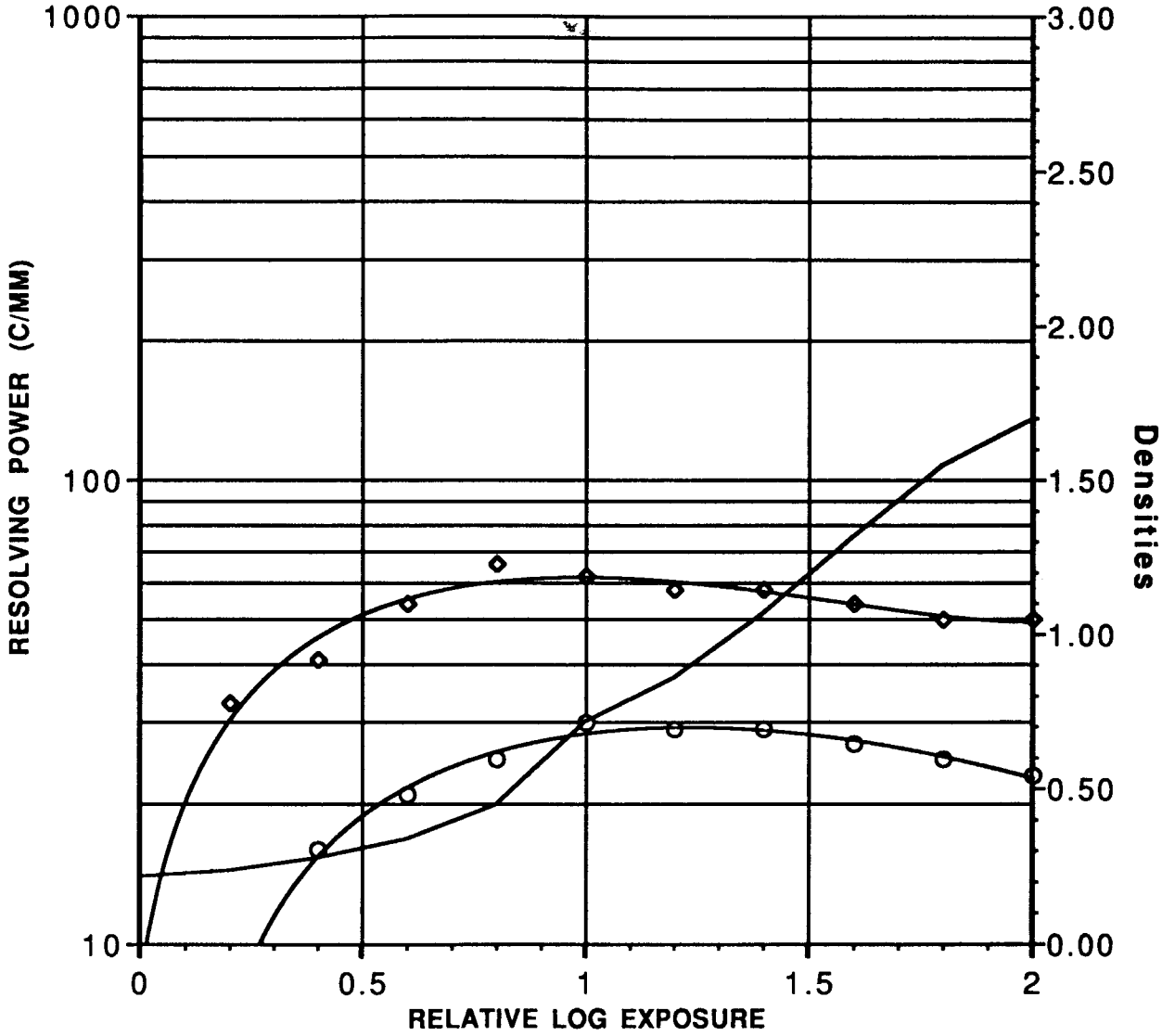
VERSAMAT 1140
641 DEVELOPER
89° 10 FPM

PEAK RESOLUTION
1000:1 TOC 56 C/MM ± 15
1.70:1 TOC 30 C/MM ± 8

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-3
LOG # 95035D

SO-050-0015



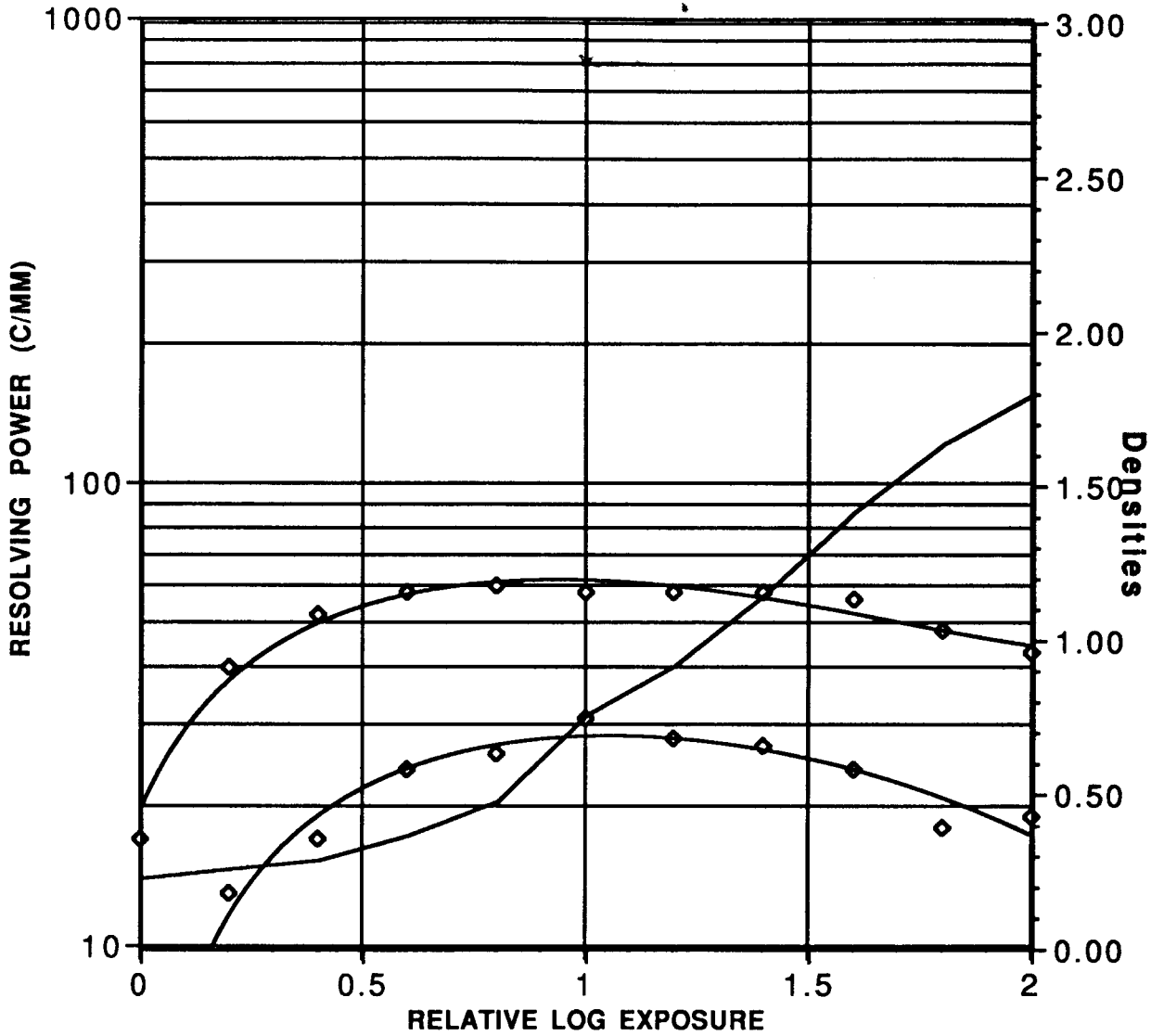
VERSAMAT 1140
641 DEVELOPER
89° 12 FPM

PEAK RESOLUTION
1000:1 TOC 62 C/MM ± 9
1.70:1 TOC 29 C/MM ± 6

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-3
LOG # 95035A

SO-050-0015

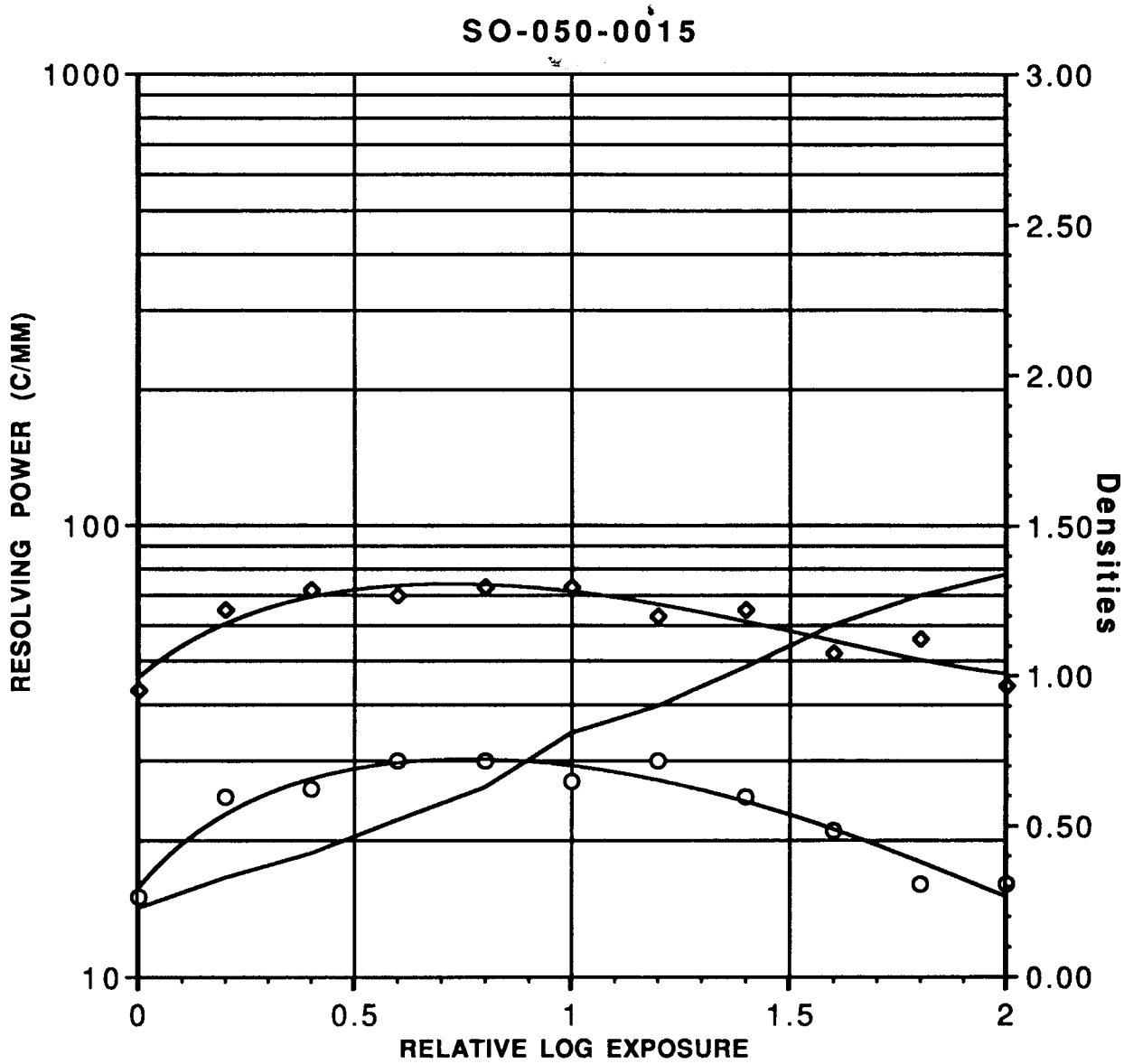


VERSAMAT 1140
641 DEVELOPER
89° 20 FPM

PEAK RESOLUTION
1000:1 TOC 62 C/MM ± 7
1.70:1 TOC 28 C/MM ± 3

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-3
LOG # 95035BC



VERSAMAT 1140
641 DEVELOPER
89° 40 FPM

PEAK RESOLUTION
1000:1 TOC 74 C/MM ± 12
1.70:1 TOC 30 C/MM ± 3

RESOLVING POWER ± VALUES ARE AVERAGE OF
± 2 SIGMA VALUES FOR EXPOSURES NEAR PEAK

M&P # 091895-3
LOG # 95035B